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Kerr et al.

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(45) Date of Patent: Feb. 16, 2016

(54) **AUTOMATIC LASER SHUTDOWN AND RECOVERY IN RESPONSE TO A LINK BREAK**

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(73) Assignee: **Infinera Corporation**, Sunnyvale, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1141 days.

(21) Appl. No.: **12/239,857**

(22) Filed: **Sep. 29, 2008**

(65) **Prior Publication Data**

US 2010/0080553 A1 Apr. 1, 2010

(51) **Int. Cl.**

H04B 17/00	(2015.01)
H04B 10/077	(2013.01)
H04B 10/071	(2013.01)

(52) **U.S. Cl.**

CPC ***H04B 10/0773*** (2013.01); ***H04B 10/071*** (2013.01)

(58) **Field of Classification Search**

CPC H04B 10/0773
USPC 398/13, 17, 20, 10, 30, 31, 32, 33, 34, 398/37, 38, 181, 42, 41, 177
See application file for complete search history.

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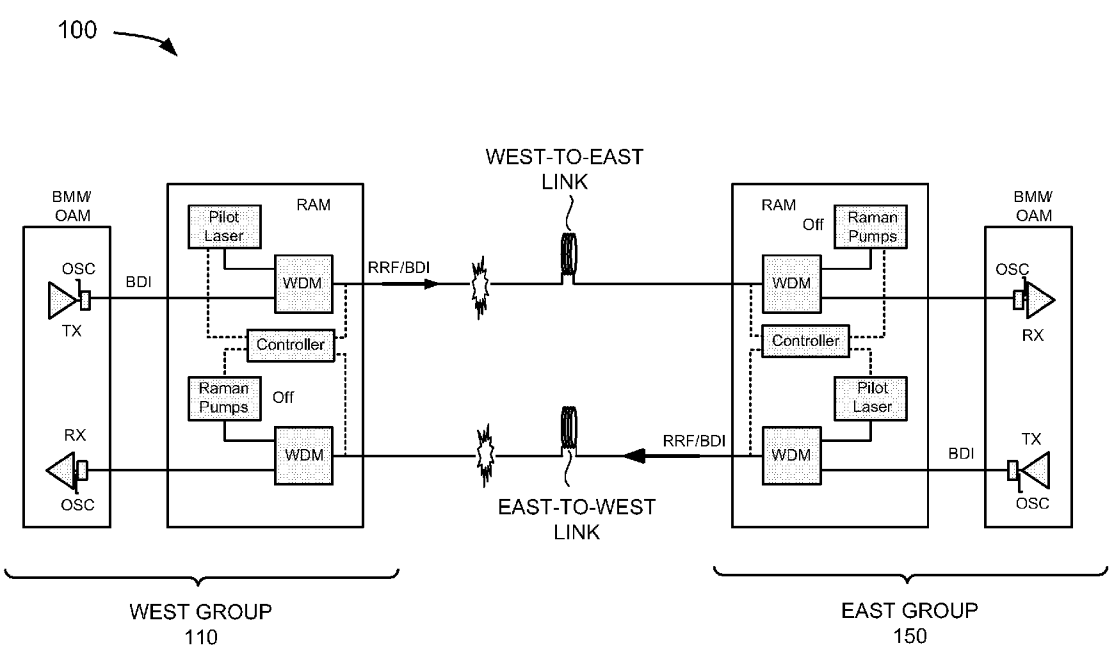
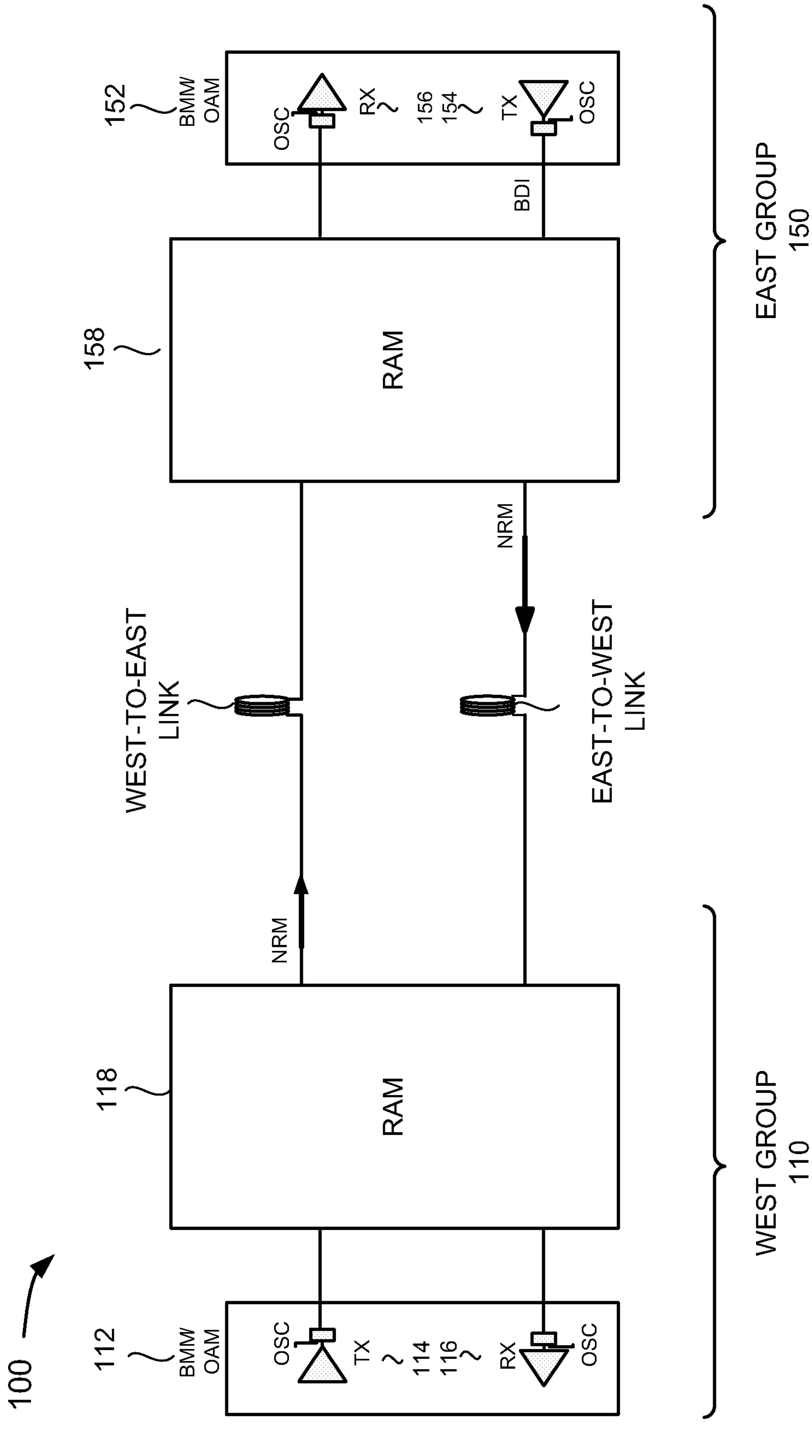
(57) **ABSTRACT**

A communication system may include a first control circuit to detect a break on a first optical link; a first optical source to supply a first optical signal on a second optical link in response to detecting the break on the first optical link, the first optical signal propagating in a first direction on the second optical link; a second control circuit to detect a presence of the first optical signal on the second optical link, and output a control signal in response to detecting the presence of the first optical signal; and a second optical source to supply a second optical signal on the second optical link, the second optical signal propagating in a second direction opposite the first direction, where the Raman pump is disabled in response to the control signal.

25 Claims, 28 Drawing Sheets

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WEST GROUP
110
EAST GROUP
150
112
BMM/
OAM
OSC
TX
114
116
RX
OSC
118
RAM
NRM
WEST-TO-EAST
LINK
EAST-TO-WEST
LINK
NRM
158
RAM
BDI
152
BMM/
OAM
OSC
RX
156
154
TX
OSC

FIG. 1

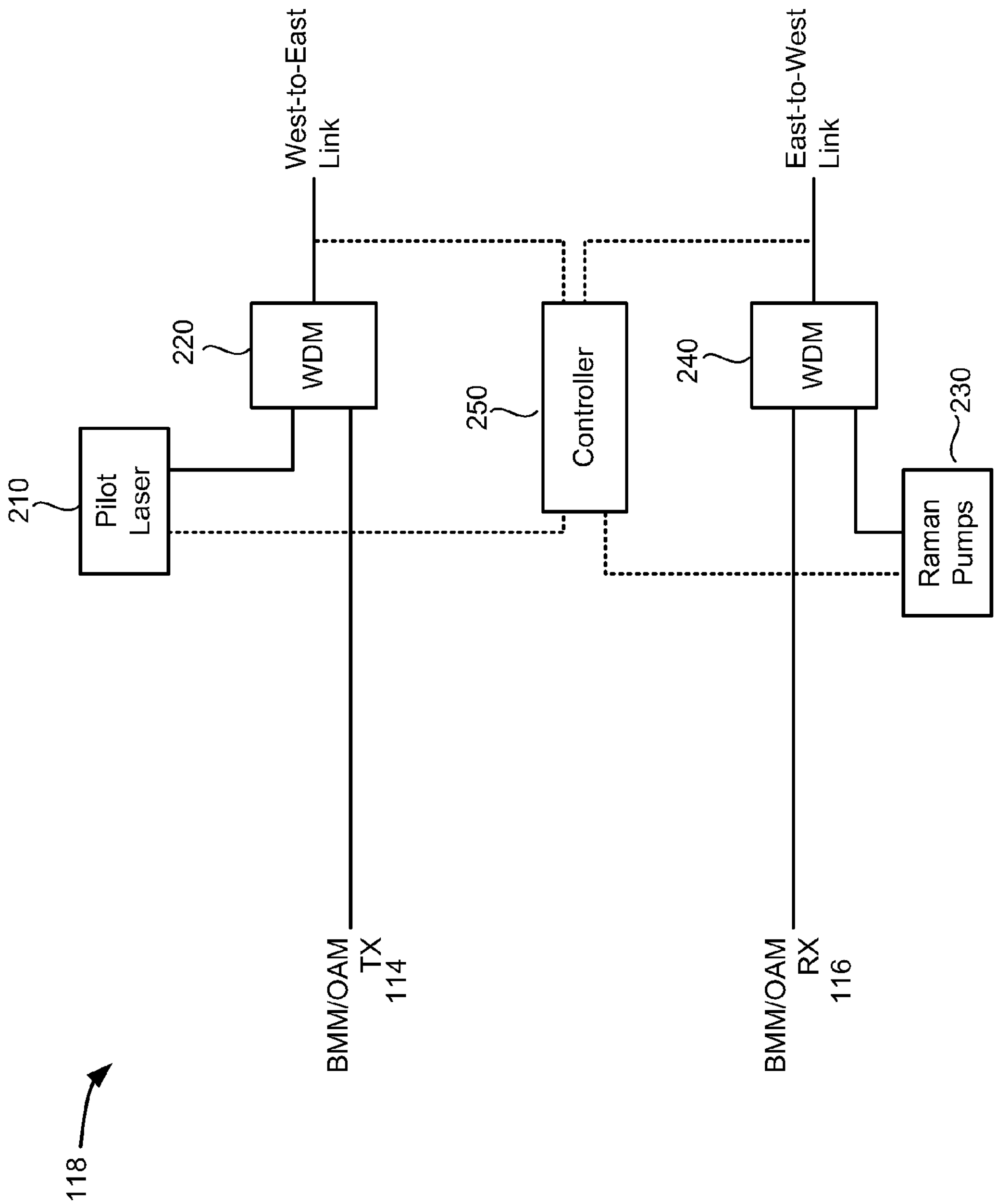

118
BMM/OAM TX 114
BMM/OAM RX 116
210
Pilot Laser
220
WDM
West-to-East Link
250
Controller
240
WDM
East-to-West Link
230
Raman Pumps

FIG. 2

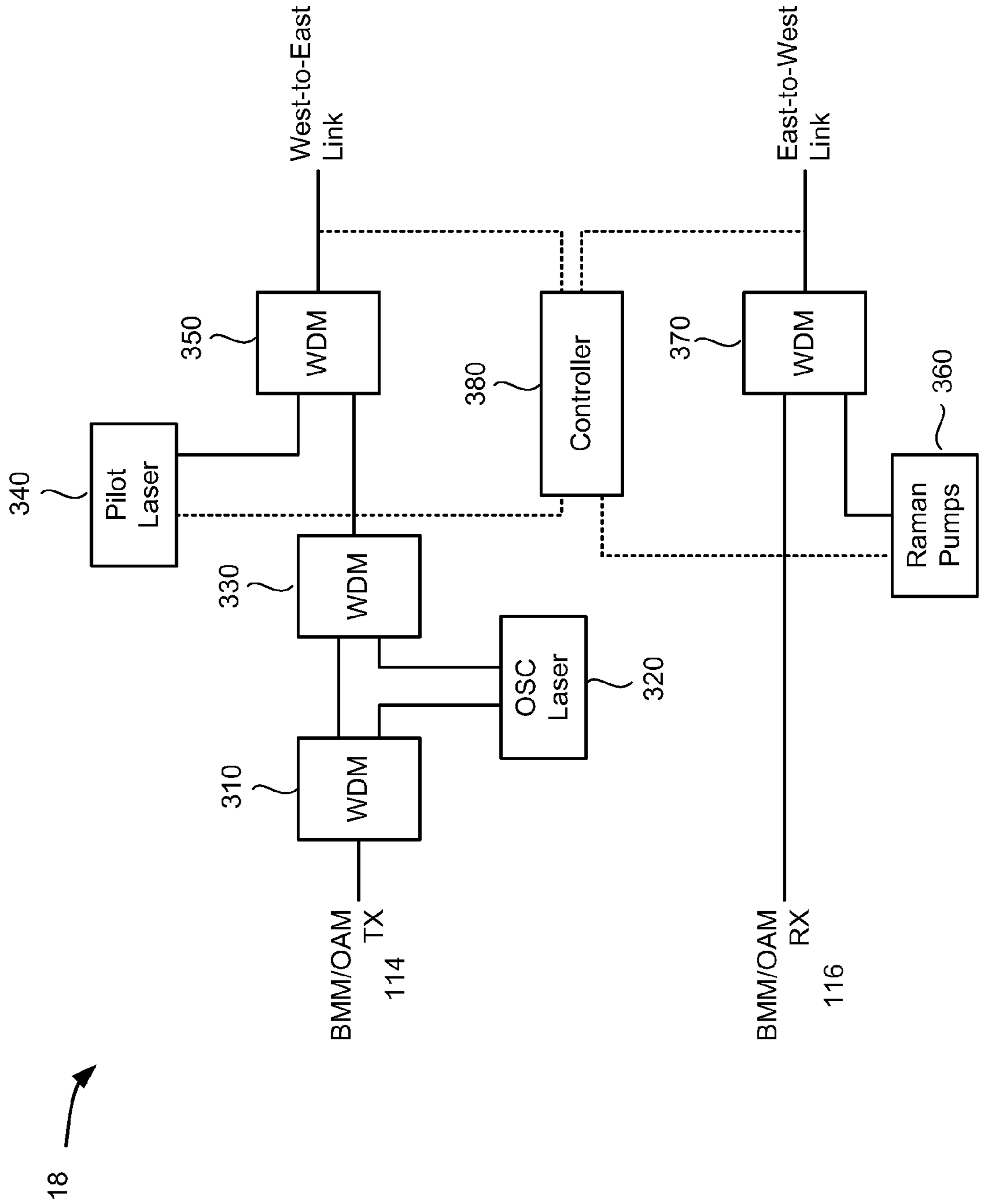

West-to-East Link
East-to-West Link
350
WDM
380
Controller
370
WDM
360
340
Pilot Laser
Raman Pumps
330
WDM
OSC Laser
320
310
WDM
BMM/OAM TX
114
BMM/OAM RX
116
118

FIG. 3

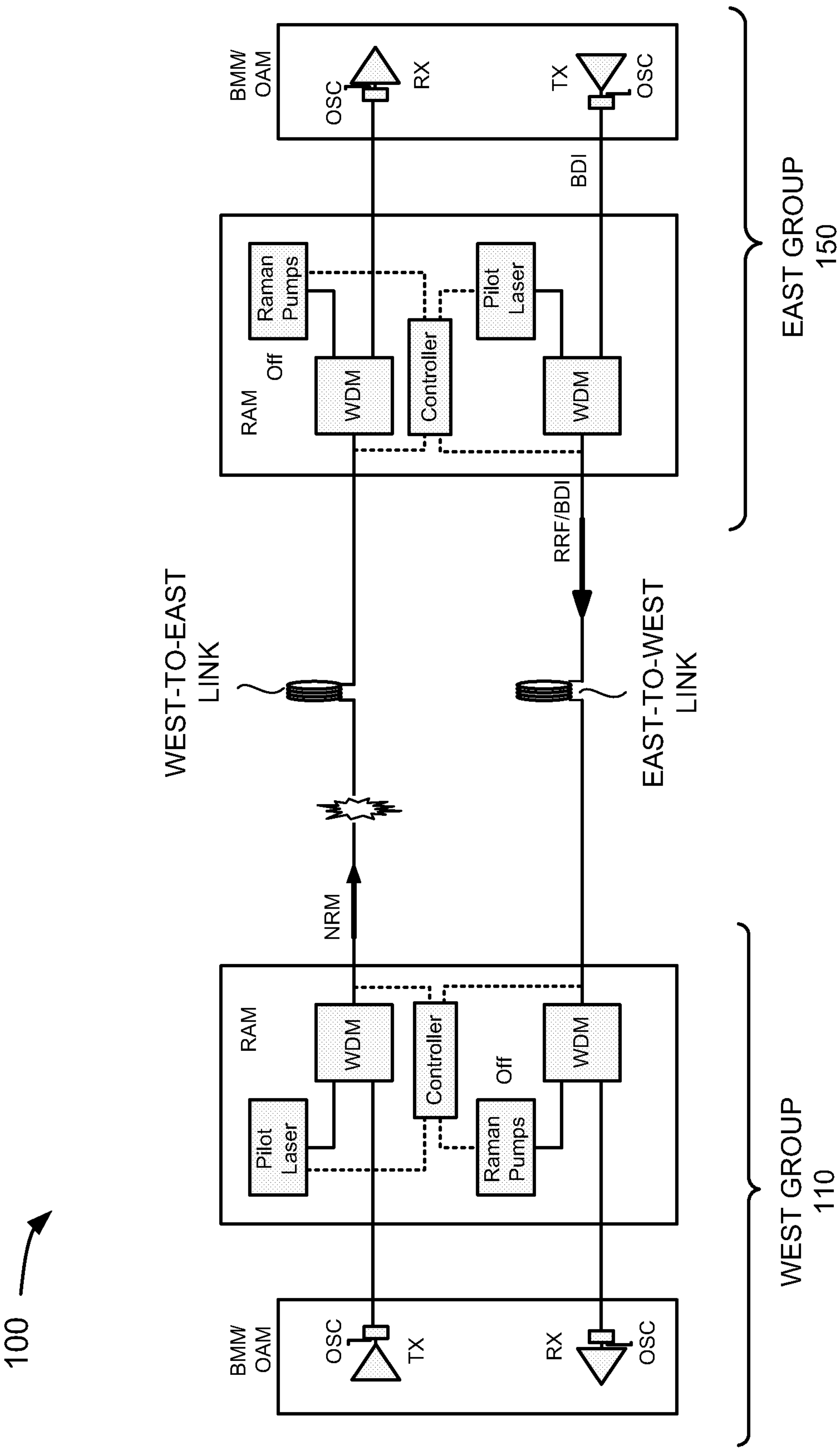

100
BMM/ OAM
OSC
TX
RX
OSC
RAM
Pilot Laser
WDM
Controller
Raman Pumps
Off
WDM
WEST GROUP 110
NRM
WEST-TO-EAST LINK
EAST-TO-WEST LINK
RRF/BDI
RAM
Off
Raman Pumps
WDM
Controller
Pilot Laser
WDM
EAST GROUP 150
BDI
BMM/ OAM
OSC
RX
TX
OSC

FIG. 4

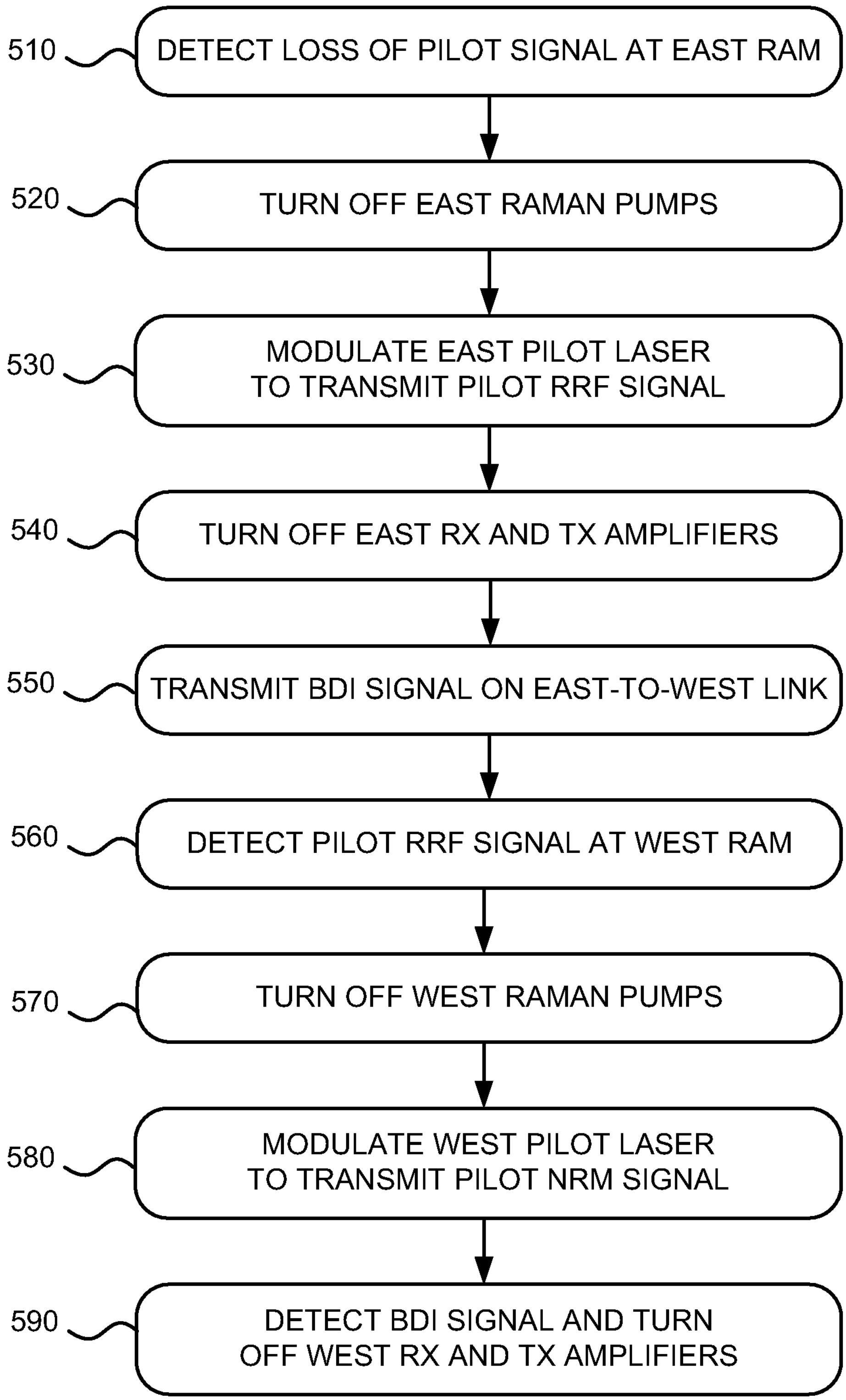

510
DETECT LOSS OF PILOT SIGNAL AT EAST RAM
520
TURN OFF EAST RAMAN PUMPS
530
MODULATE EAST PILOT LASER TO TRANSMIT PILOT RRF SIGNAL
540
TURN OFF EAST RX AND TX AMPLIFIERS
550
TRANSMIT BDI SIGNAL ON EAST-TO-WEST LINK
560
DETECT PILOT RRF SIGNAL AT WEST RAM
570
TURN OFF WEST RAMAN PUMPS
580
MODULATE WEST PILOT LASER TO TRANSMIT PILOT NRM SIGNAL
590
DETECT BDI SIGNAL AND TURN OFF WEST RX AND TX AMPLIFIERS

FIG. 5

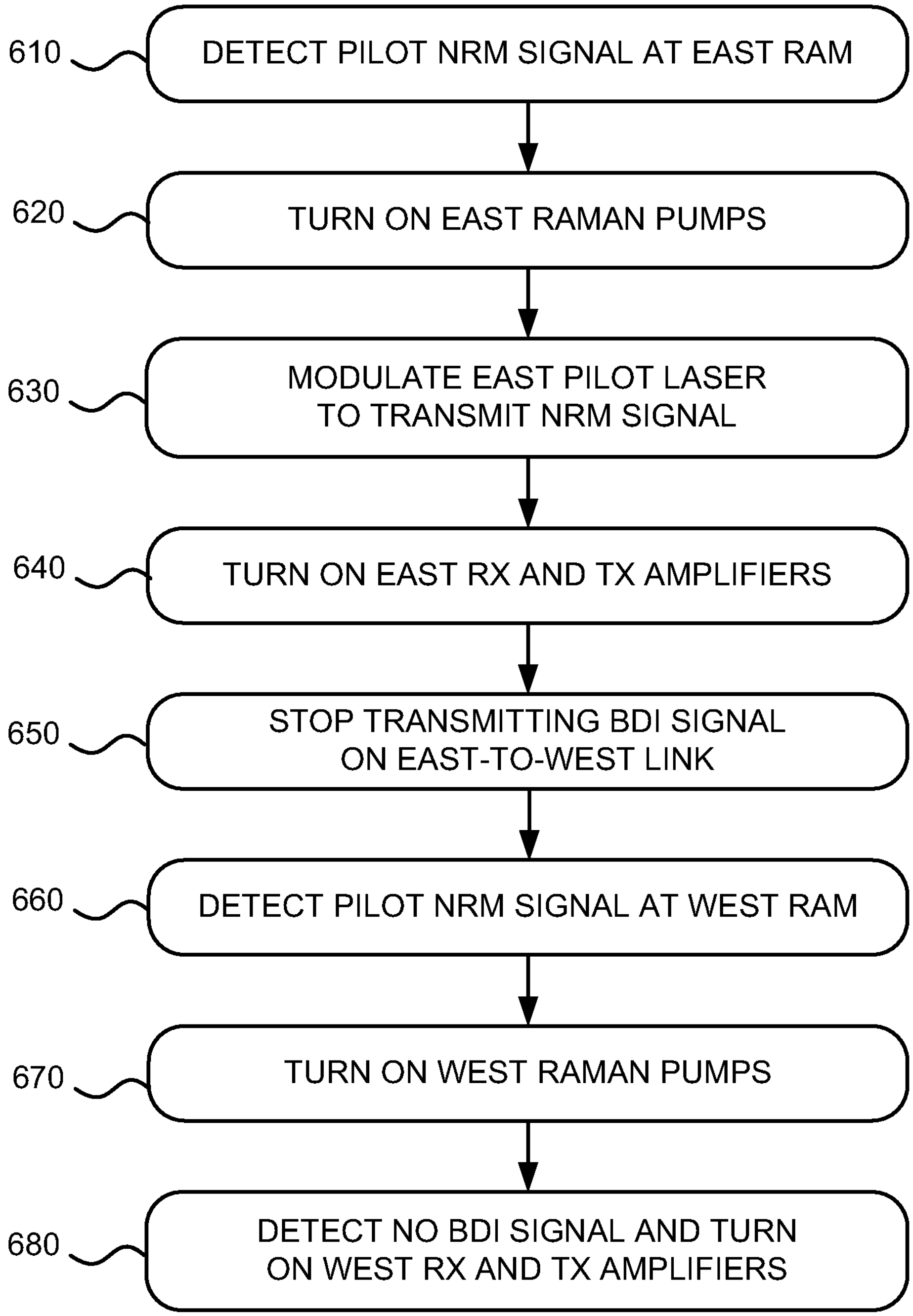
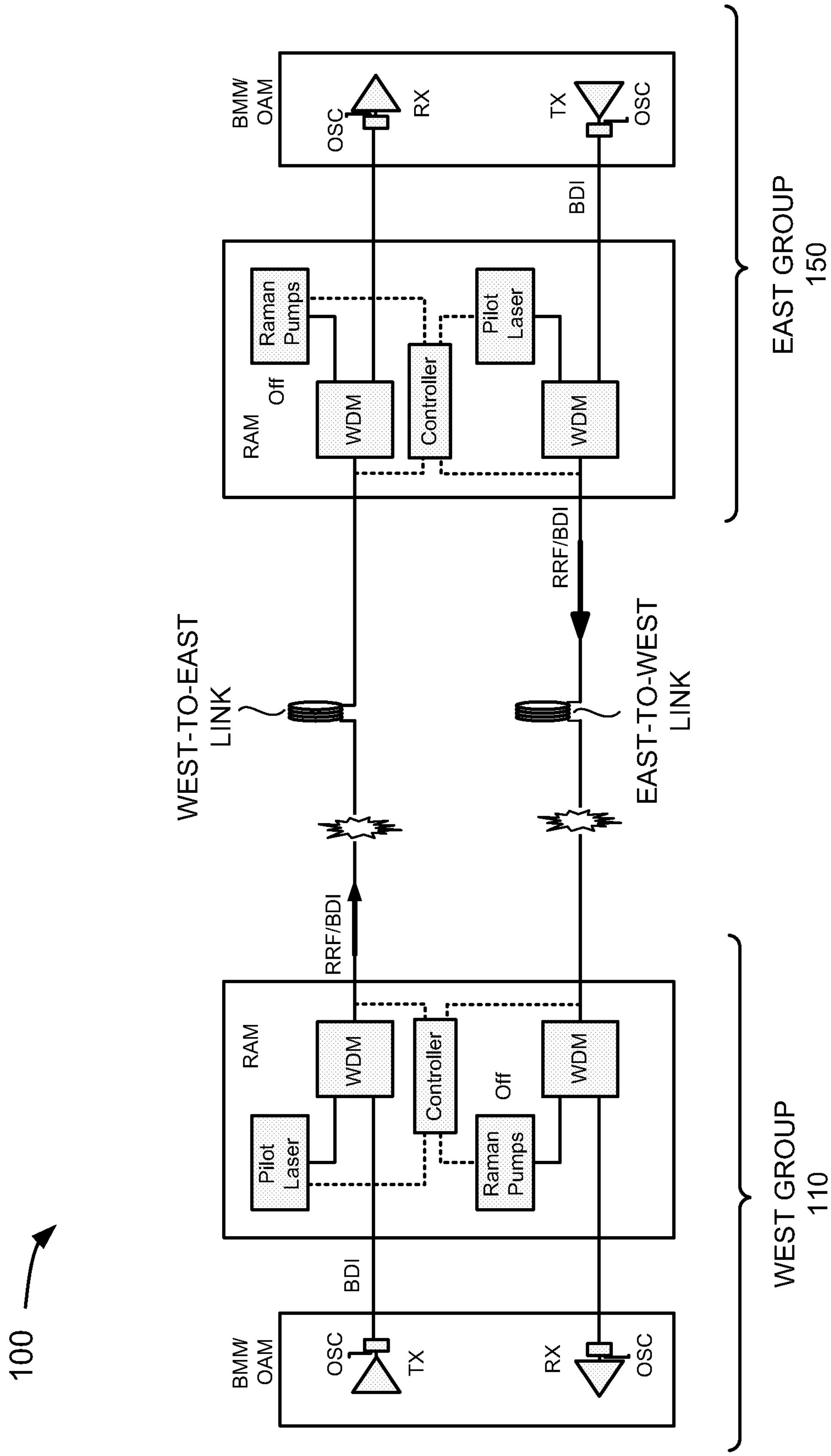

610
DETECT PILOT NRM SIGNAL AT EAST RAM
620
TURN ON EAST RAMAN PUMPS
630
MODULATE EAST PILOT LASER TO TRANSMIT NRM SIGNAL
640
TURN ON EAST RX AND TX AMPLIFIERS
650
STOP TRANSMITTING BDI SIGNAL ON EAST-TO-WEST LINK
660
DETECT PILOT NRM SIGNAL AT WEST RAM
670
TURN ON WEST RAMAN PUMPS
680
DETECT NO BDI SIGNAL AND TURN ON WEST RX AND TX AMPLIFIERS

FIG. 6



100
BMM/ OAM
OSC
TX
RX
OSC
BDI
RAM
WDM
Pilot Laser
Controller
Off
Raman Pumps
WDM
RRF/BDI
WEST-TO-EAST LINK
EAST-TO-WEST LINK
RRF/BDI
RAM
Off
Raman Pumps
WDM
Controller
Pilot Laser
WDM
BDI
BMM/ OAM
OSC
RX
TX
OSC
WEST GROUP 110
EAST GROUP 150

FIG. 7

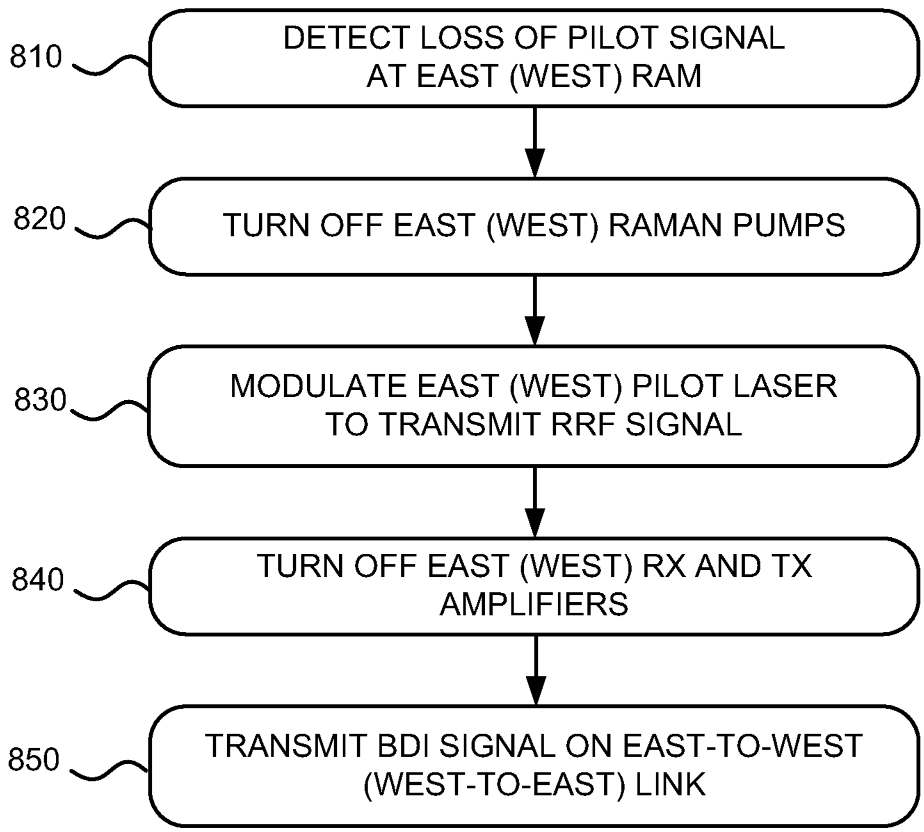

810
DETECT LOSS OF PILOT SIGNAL AT EAST (WEST) RAM
820
TURN OFF EAST (WEST) RAMAN PUMPS
830
MODULATE EAST (WEST) PILOT LASER TO TRANSMIT RRF SIGNAL
840
TURN OFF EAST (WEST) RX AND TX AMPLIFIERS
850
TRANSMIT BDI SIGNAL ON EAST-TO-WEST (WEST-TO-EAST) LINK

FIG. 8

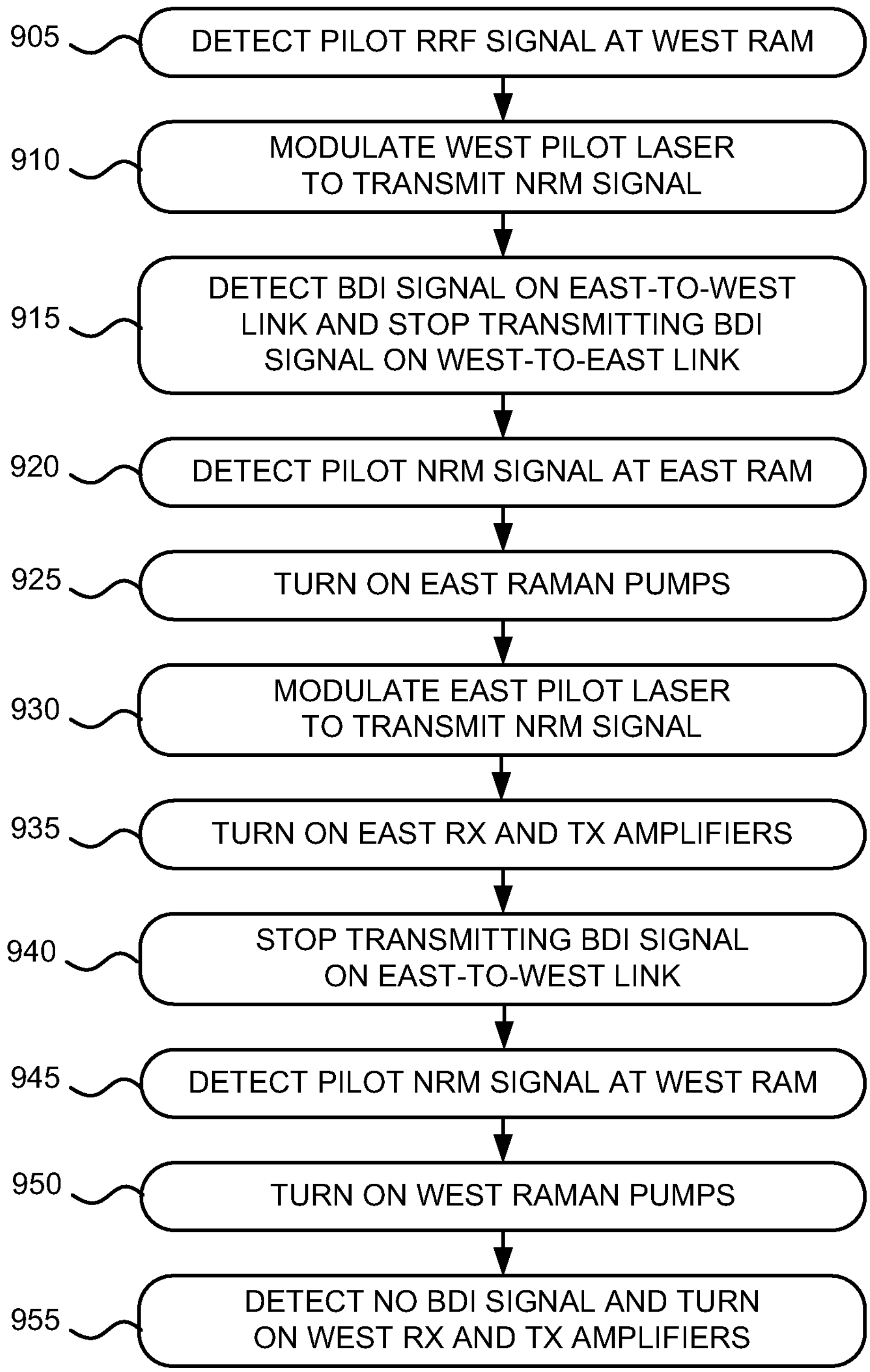

905
DETECT PILOT RRF SIGNAL AT WEST RAM
910
MODULATE WEST PILOT LASER TO TRANSMIT NRM SIGNAL
915
DETECT BDI SIGNAL ON EAST-TO-WEST LINK AND STOP TRANSMITTING BDI SIGNAL ON WEST-TO-EAST LINK
920
DETECT PILOT NRM SIGNAL AT EAST RAM
925
TURN ON EAST RAMAN PUMPS
930
MODULATE EAST PILOT LASER TO TRANSMIT NRM SIGNAL
935
TURN ON EAST RX AND TX AMPLIFIERS
940
STOP TRANSMITTING BDI SIGNAL ON EAST-TO-WEST LINK
945
DETECT PILOT NRM SIGNAL AT WEST RAM
950
TURN ON WEST RAMAN PUMPS
955
DETECT NO BDI SIGNAL AND TURN ON WEST RX AND TX AMPLIFIERS

FIG. 9

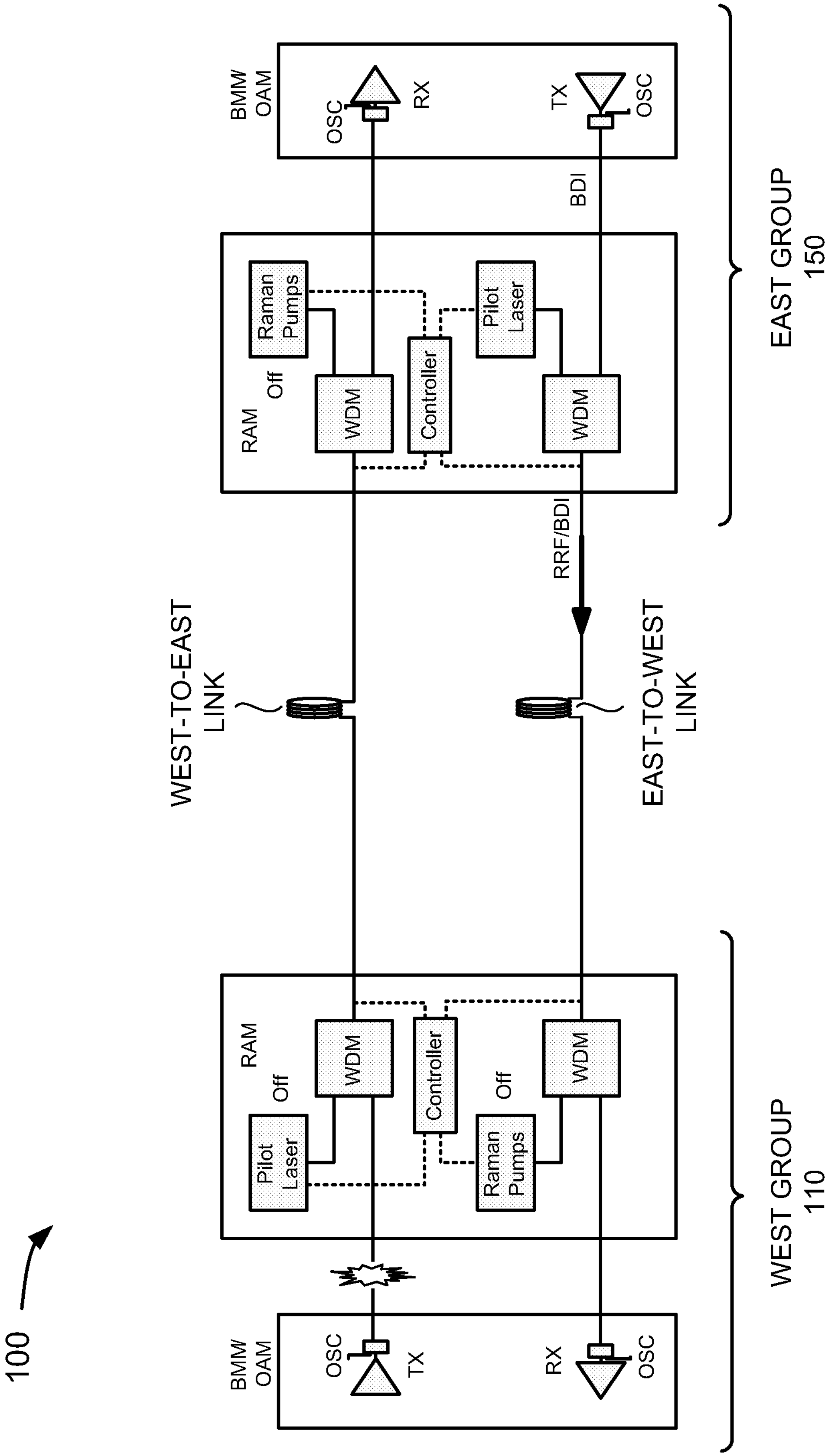

100
BMM/ OAM
OSC
TX
RX
OSC
RAM
Off
WDM
Pilot Laser
Controller
Off
Raman Pumps
WDM
WEST GROUP 110
WEST-TO-EAST LINK
EAST-TO-WEST LINK
RRF/BDI
RAM
Off
WDM
Raman Pumps
Controller
Pilot Laser
WDM
BDI
EAST GROUP 150
BMM/ OAM
OSC
RX
TX
OSC

FIG. 10

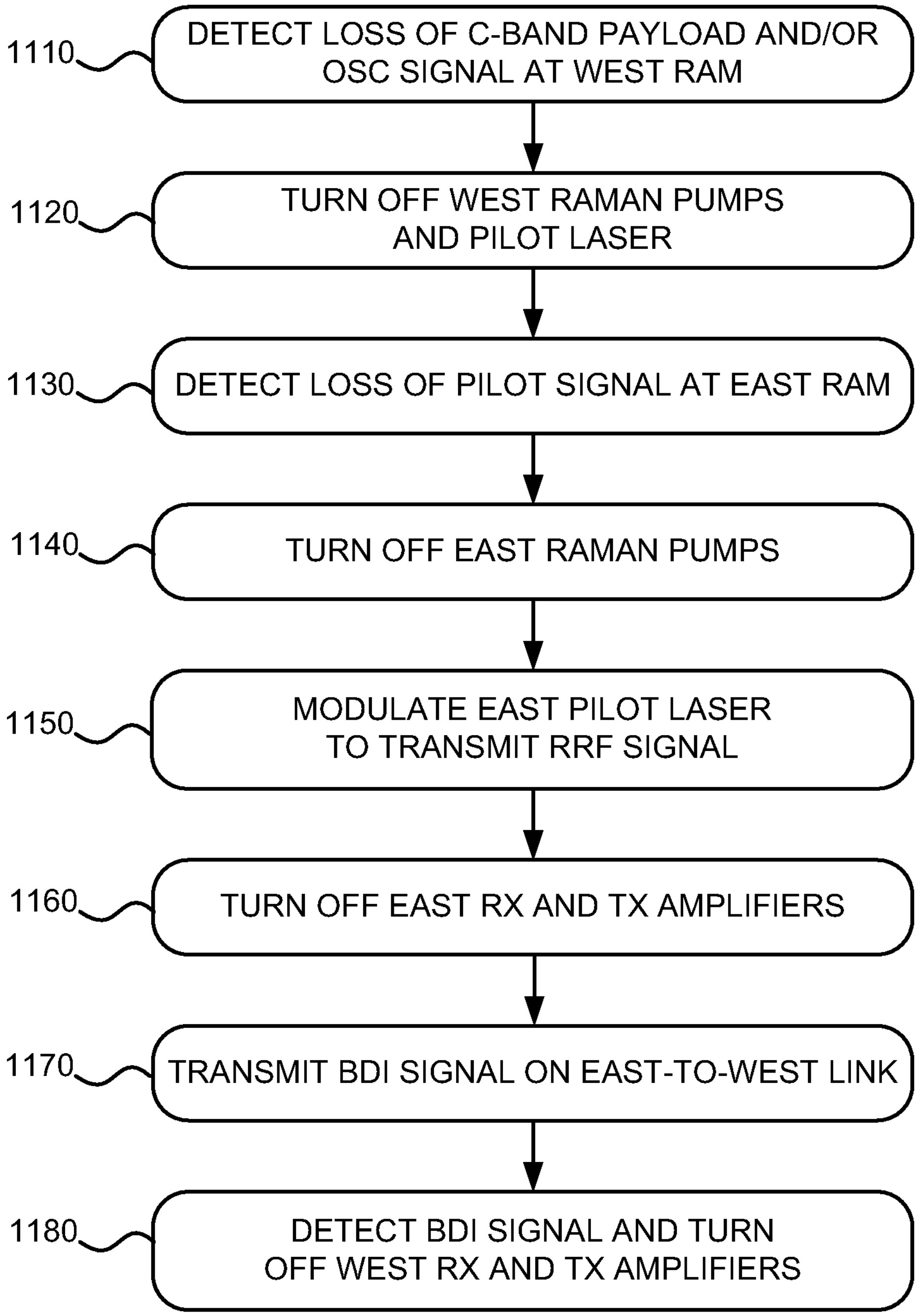

1110
DETECT LOSS OF C-BAND PAYLOAD AND/OR OSC SIGNAL AT WEST RAM
1120
TURN OFF WEST RAMAN PUMPS AND PILOT LASER
1130
DETECT LOSS OF PILOT SIGNAL AT EAST RAM
1140
TURN OFF EAST RAMAN PUMPS
1150
MODULATE EAST PILOT LASER TO TRANSMIT RRF SIGNAL
1160
TURN OFF EAST RX AND TX AMPLIFIERS
1170
TRANSMIT BDI SIGNAL ON EAST-TO-WEST LINK
1180
DETECT BDI SIGNAL AND TURN OFF WEST RX AND TX AMPLIFIERS

FIG. 11

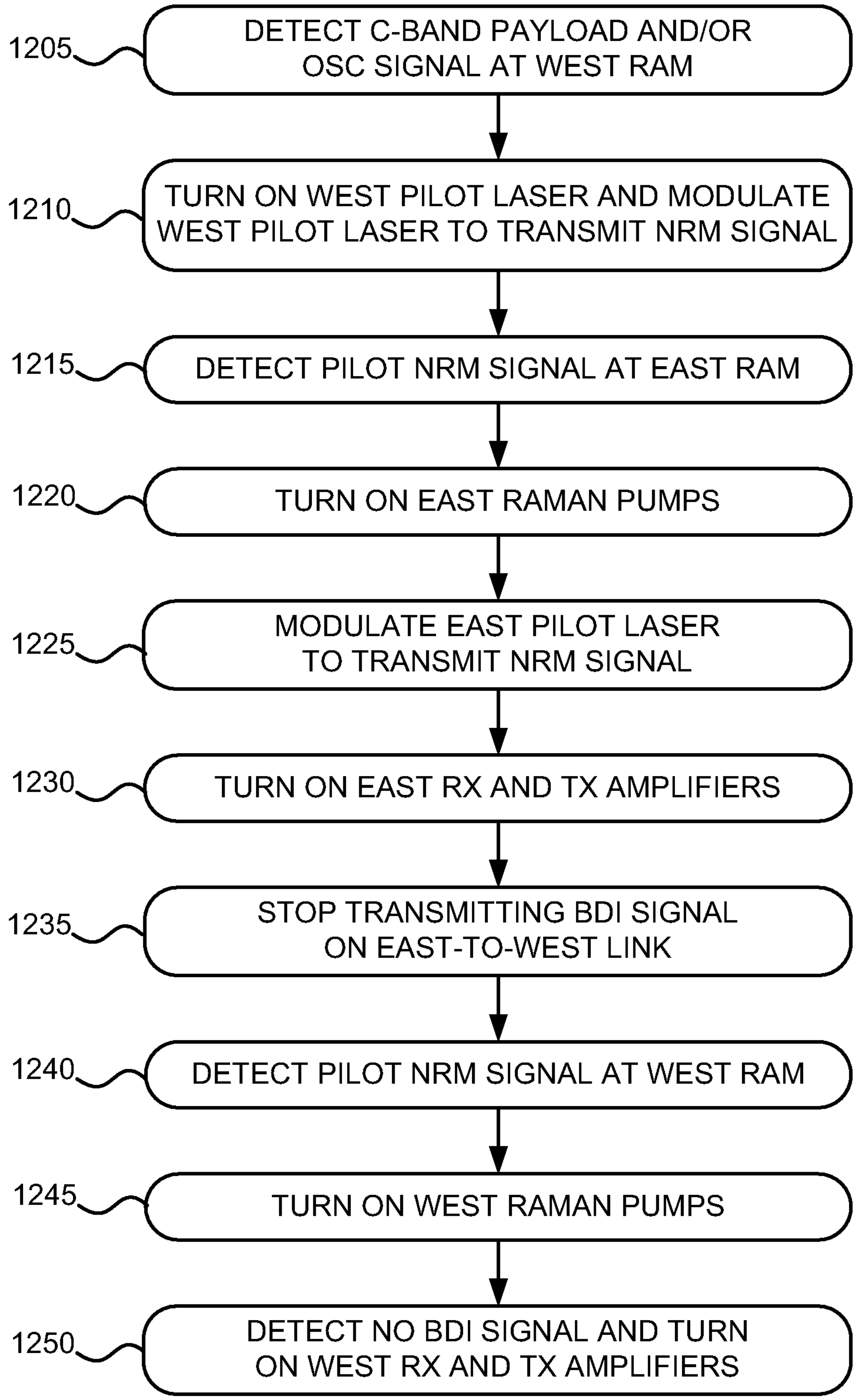
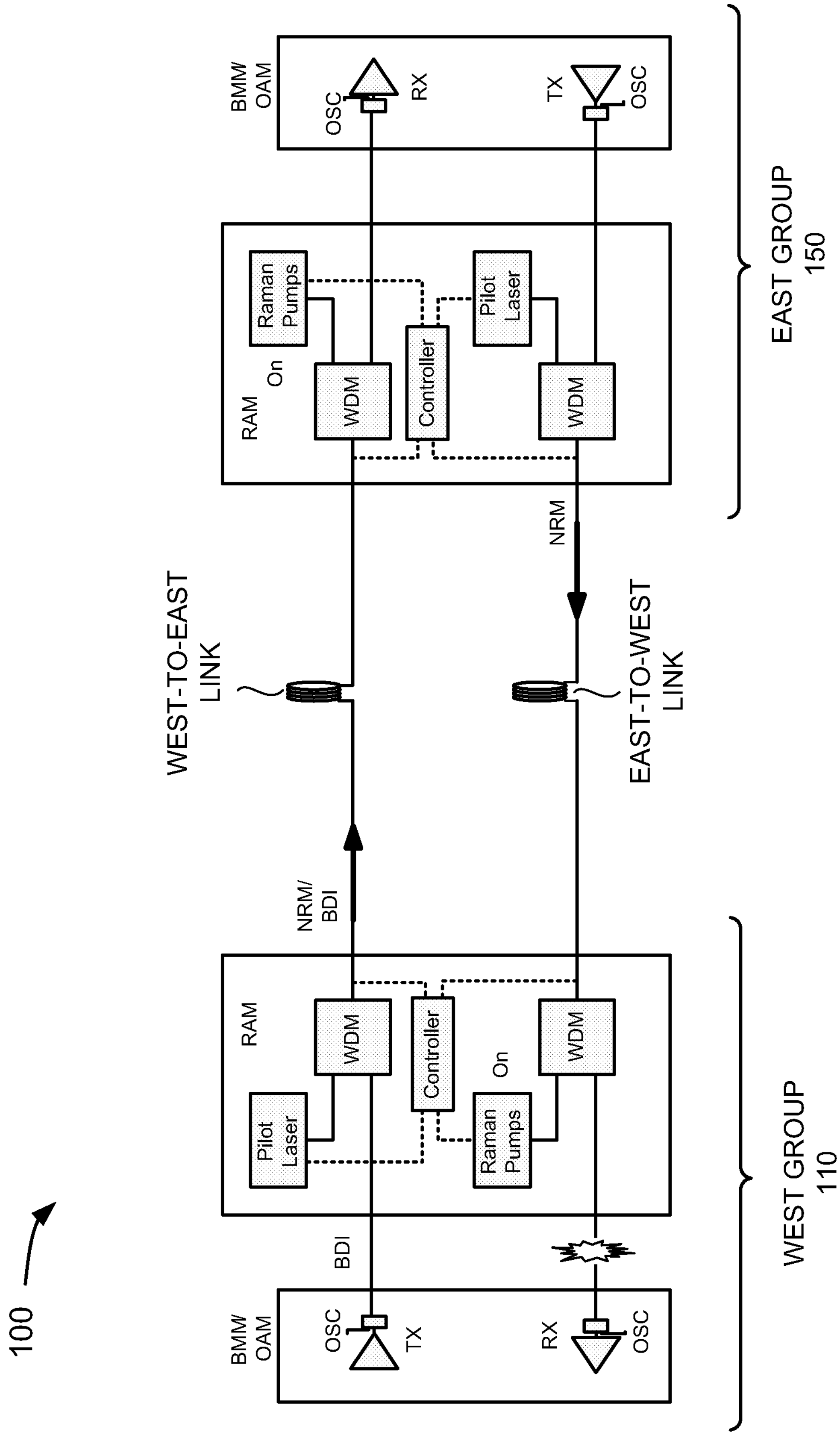

1205
DETECT C-BAND PAYLOAD AND/OR OSC SIGNAL AT WEST RAM
1210
TURN ON WEST PILOT LASER AND MODULATE WEST PILOT LASER TO TRANSMIT NRM SIGNAL
1215
DETECT PILOT NRM SIGNAL AT EAST RAM
1220
TURN ON EAST RAMAN PUMPS
1225
MODULATE EAST PILOT LASER TO TRANSMIT NRM SIGNAL
1230
TURN ON EAST RX AND TX AMPLIFIERS
1235
STOP TRANSMITTING BDI SIGNAL ON EAST-TO-WEST LINK
1240
DETECT PILOT NRM SIGNAL AT WEST RAM
1245
TURN ON WEST RAMAN PUMPS
1250
DETECT NO BDI SIGNAL AND TURN ON WEST RX AND TX AMPLIFIERS

FIG. 12



100
BMM/ OAM
OSC
TX
RX
OSC
BDI
RAM
Pilot Laser
WDM
Controller
On
Raman Pumps
WDM
WEST GROUP 110
NRM/ BDI
WEST-TO-EAST LINK
EAST-TO-WEST LINK
NRM
RAM
On
Raman Pumps
WDM
Controller
Pilot Laser
WDM
EAST GROUP 150
BMM/ OAM
OSC
RX
TX
OSC

FIG. 13

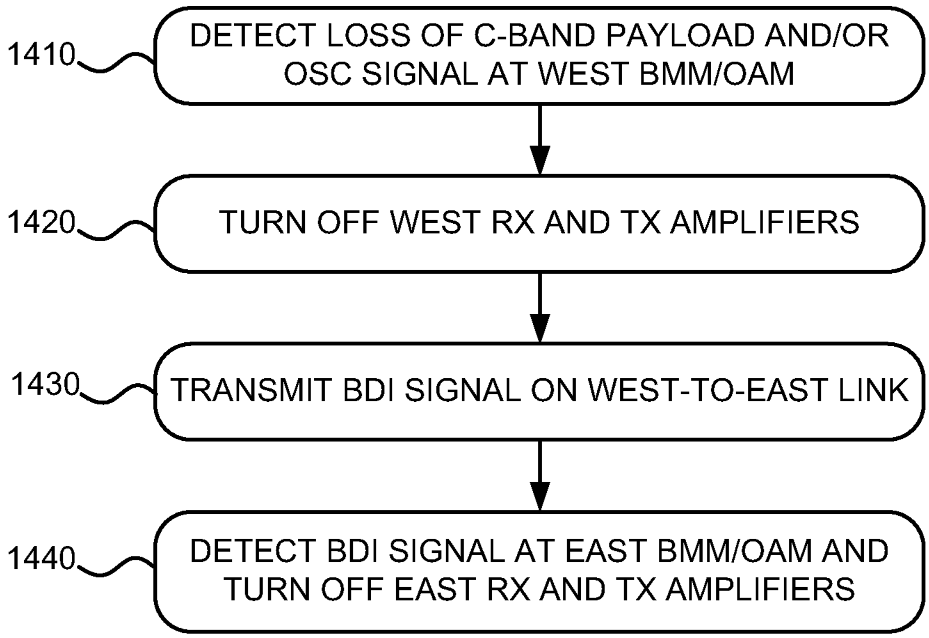

1410
DETECT LOSS OF C-BAND PAYLOAD AND/OR OSC SIGNAL AT WEST BMM/OAM
1420
TURN OFF WEST RX AND TX AMPLIFIERS
1430
TRANSMIT BDI SIGNAL ON WEST-TO-EAST LINK
1440
DETECT BDI SIGNAL AT EAST BMM/OAM AND TURN OFF EAST RX AND TX AMPLIFIERS

FIG. 14

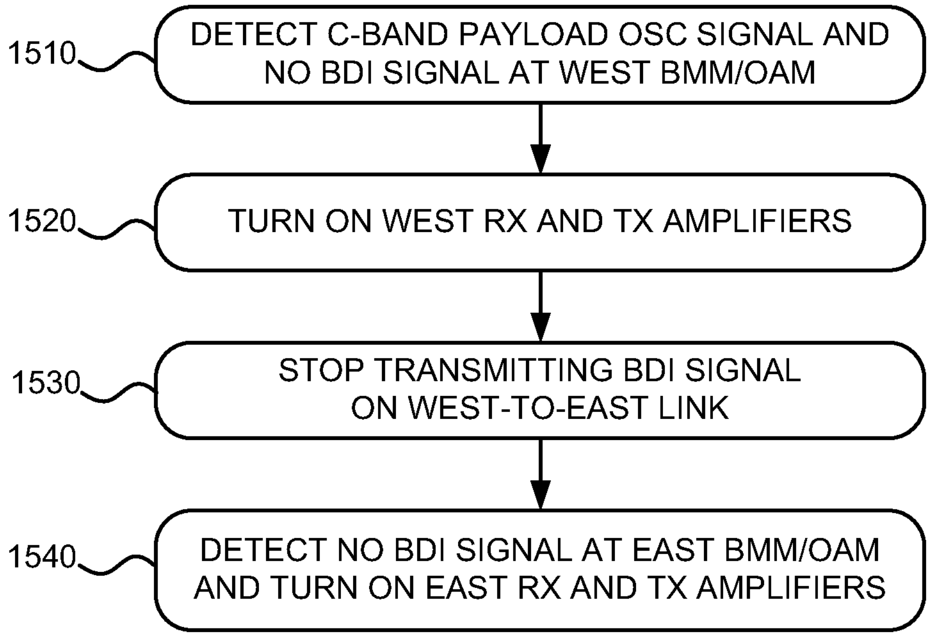

1510
DETECT C-BAND PAYLOAD OSC SIGNAL AND NO BDI SIGNAL AT WEST BMM/OAM
1520
TURN ON WEST RX AND TX AMPLIFIERS
1530
STOP TRANSMITTING BDI SIGNAL ON WEST-TO-EAST LINK
1540
DETECT NO BDI SIGNAL AT EAST BMM/OAM AND TURN ON EAST RX AND TX AMPLIFIERS

FIG. 15

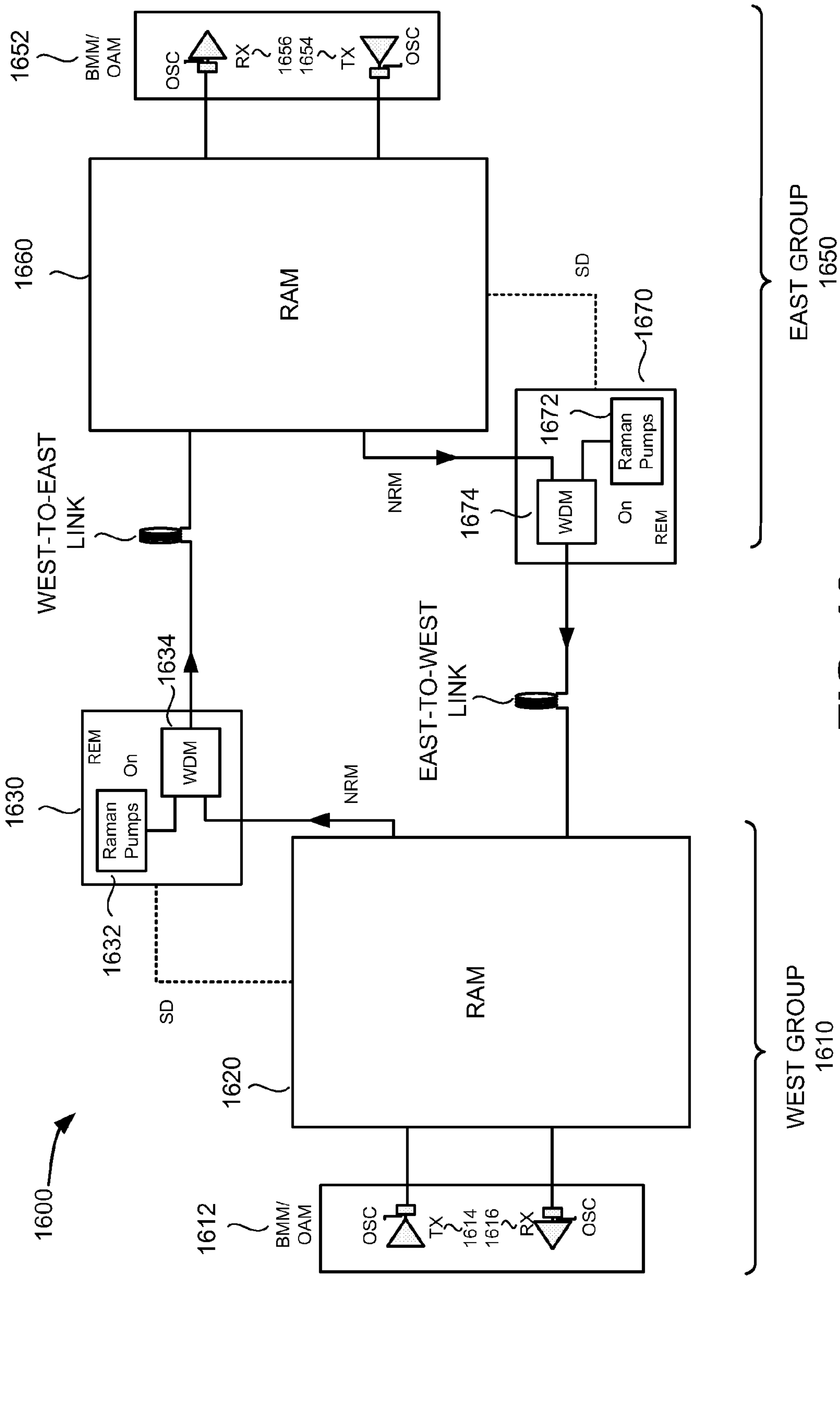

1600
1612
BMM/
OAM
OSC
TX
1614
1616
RX
OSC
1620
RAM
WEST GROUP
1610
SD
1632
1630
Raman
Pumps
REM
On
WDM
NRM
1634
WEST-TO-EAST
LINK
EAST-TO-WEST
LINK
1660
RAM
1652
BMM/
OAM
OSC
RX
1656
1654
TX
OSC
SD
1670
1672
Raman
Pumps
NRM
1674
WDM
On
REM
EAST GROUP
1650

FIG. 16

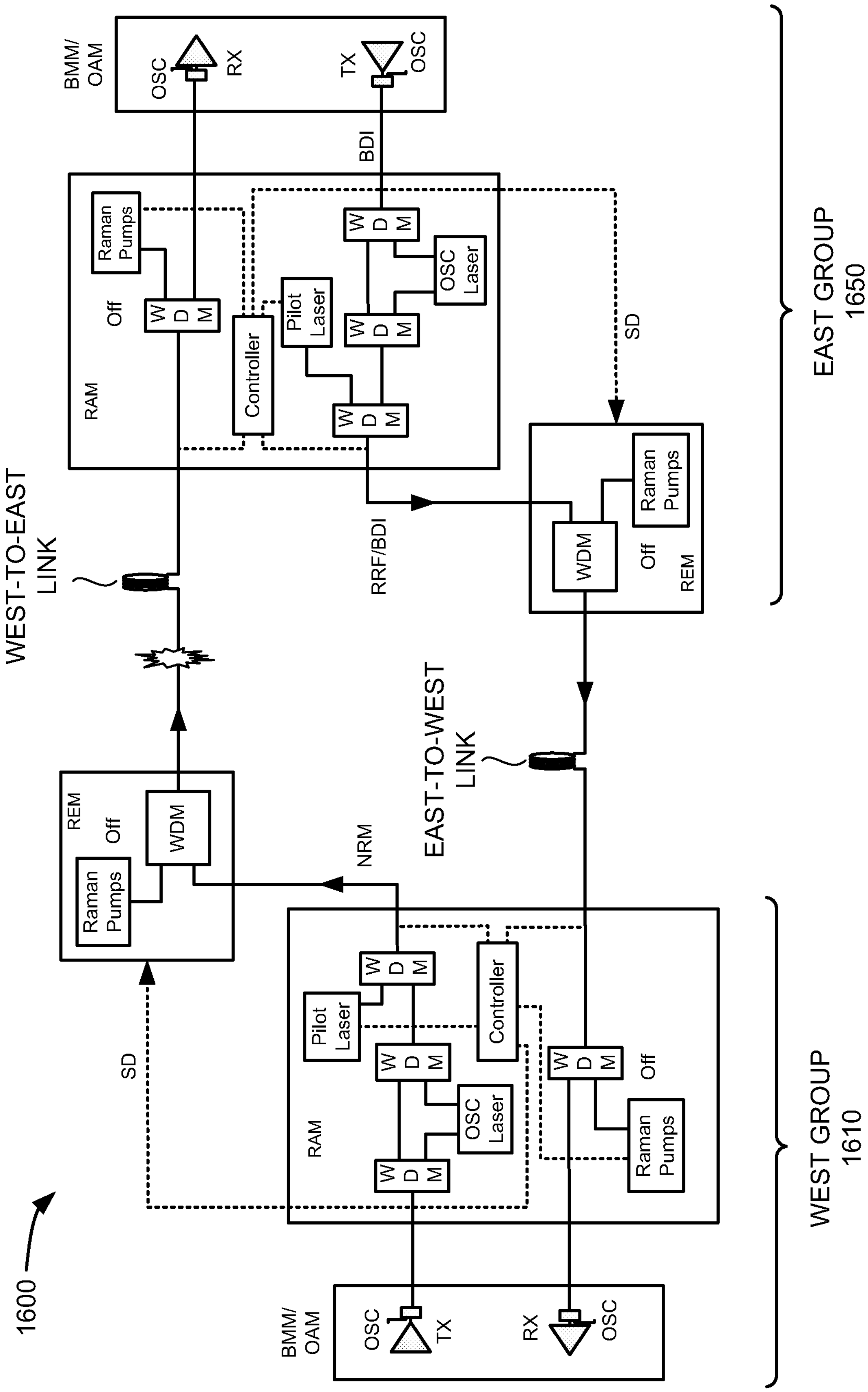

1600
BMM/ OAM
OSC
TX
RX
OSC
RAM
WDM
Pilot Laser
OSC Laser
Controller
Raman Pumps
Off
SD
NRM
REM
WDM
Off
Raman Pumps
WEST-TO-EAST LINK
EAST-TO-WEST LINK
RRF/BDI
BDI
Raman Pumps
Off
RAM
Controller
Pilot Laser
OSC Laser
WDM
SD
REM
WDM
Off
Raman Pumps
BMM/ OAM
OSC
RX
TX
OSC
WEST GROUP 1610
EAST GROUP 1650

FIG. 17

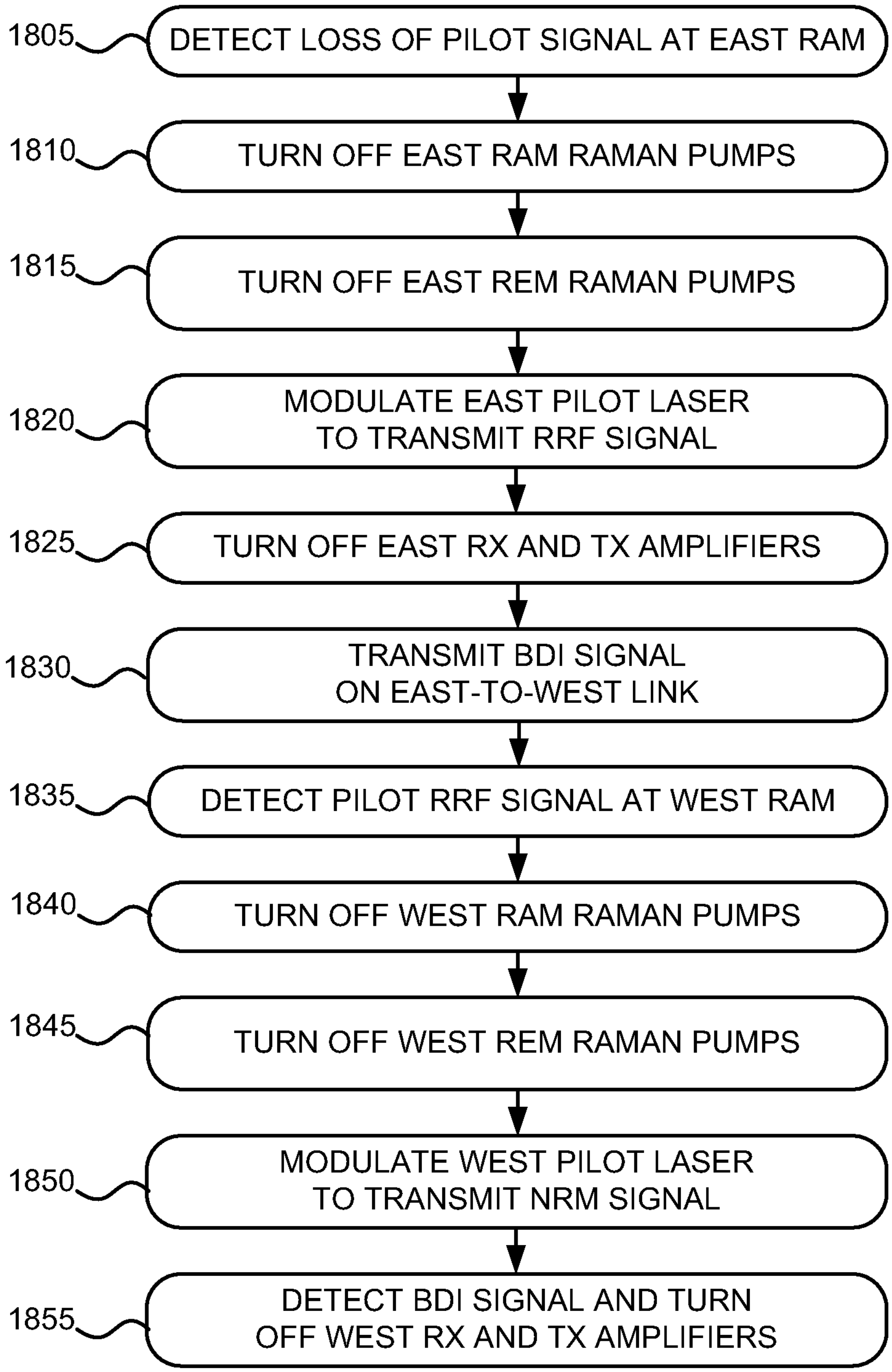

1805
DETECT LOSS OF PILOT SIGNAL AT EAST RAM
1810
TURN OFF EAST RAM RAMAN PUMPS
1815
TURN OFF EAST REM RAMAN PUMPS
1820
MODULATE EAST PILOT LASER TO TRANSMIT RRF SIGNAL
1825
TURN OFF EAST RX AND TX AMPLIFIERS
1830
TRANSMIT BDI SIGNAL ON EAST-TO-WEST LINK
1835
DETECT PILOT RRF SIGNAL AT WEST RAM
1840
TURN OFF WEST RAM RAMAN PUMPS
1845
TURN OFF WEST REM RAMAN PUMPS
1850
MODULATE WEST PILOT LASER TO TRANSMIT NRM SIGNAL
1855
DETECT BDI SIGNAL AND TURN OFF WEST RX AND TX AMPLIFIERS

FIG. 18

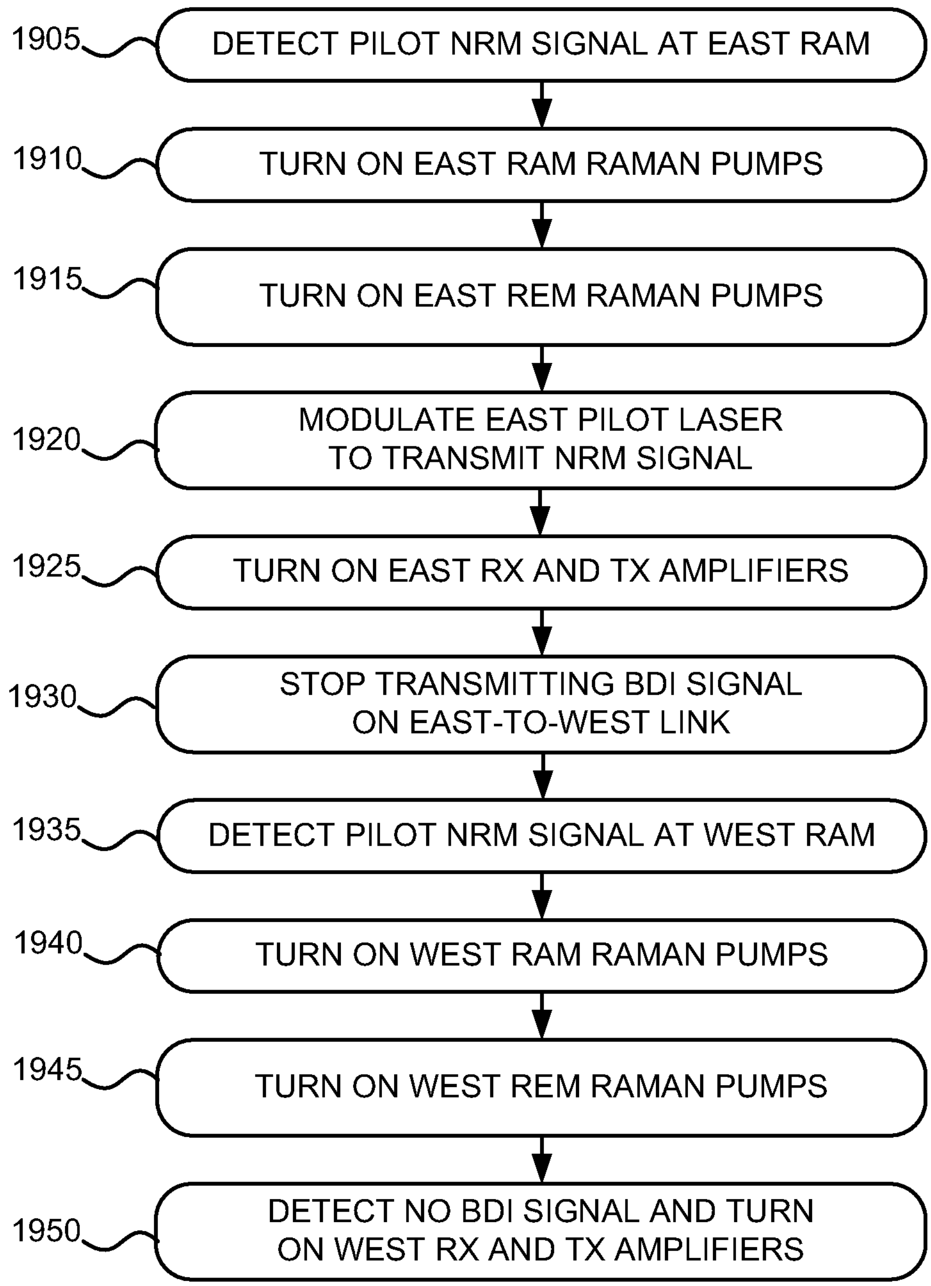

1905
DETECT PILOT NRM SIGNAL AT EAST RAM
1910
TURN ON EAST RAM RAMAN PUMPS
1915
TURN ON EAST REM RAMAN PUMPS
1920
MODULATE EAST PILOT LASER TO TRANSMIT NRM SIGNAL
1925
TURN ON EAST RX AND TX AMPLIFIERS
1930
STOP TRANSMITTING BDI SIGNAL ON EAST-TO-WEST LINK
1935
DETECT PILOT NRM SIGNAL AT WEST RAM
1940
TURN ON WEST RAM RAMAN PUMPS
1945
TURN ON WEST REM RAMAN PUMPS
1950
DETECT NO BDI SIGNAL AND TURN ON WEST RX AND TX AMPLIFIERS

FIG. 19

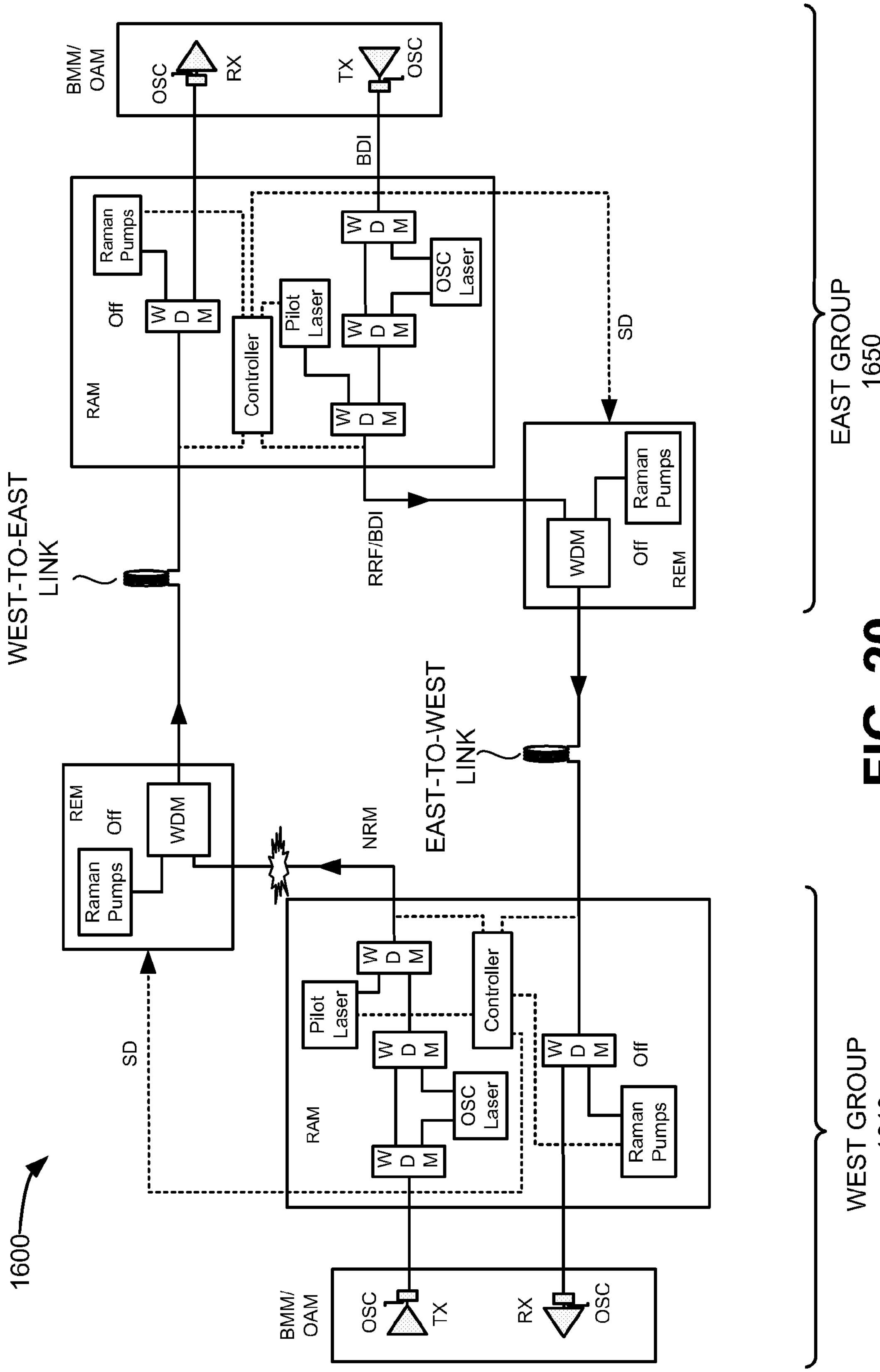

1600
BMM/
OAM
OSC
TX
RX
OSC
RAM
W
D
M
OSC
Laser
Pilot
Laser
Controller
Off
Raman
Pumps
SD
REM
Off
WDM
Raman
Pumps
NRM
WEST-TO-EAST
LINK
EAST-TO-WEST
LINK
RAM
Off
Raman
Pumps
Controller
Pilot
Laser
OSC
Laser
SD
RRF/BDI
REM
Off
WDM
Raman
Pumps
BDI
BMM/
OAM
OSC
RX
TX
OSC
WEST GROUP
1610
EAST GROUP
1650

FIG. 20

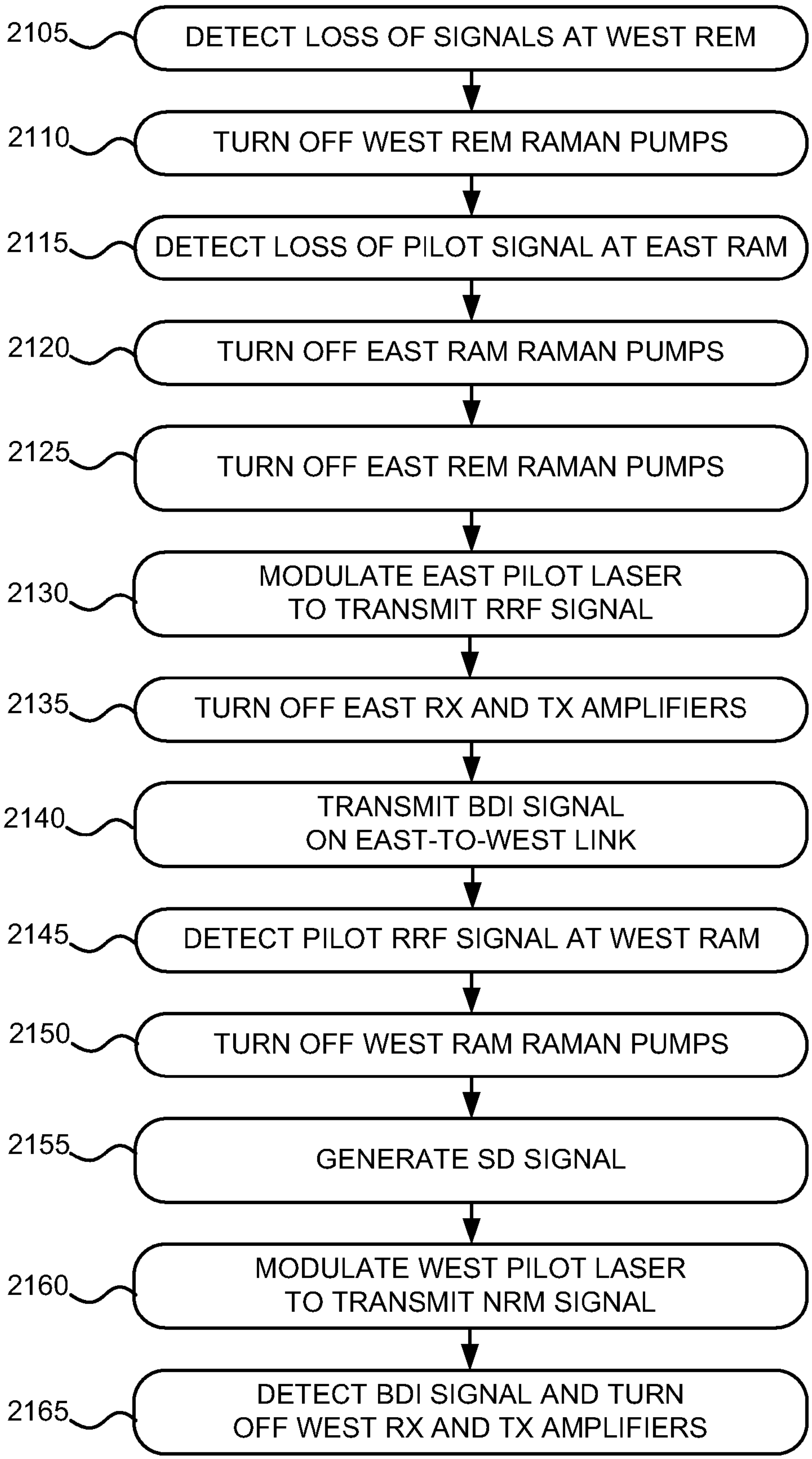

2105
DETECT LOSS OF SIGNALS AT WEST REM
2110
TURN OFF WEST REM RAMAN PUMPS
2115
DETECT LOSS OF PILOT SIGNAL AT EAST RAM
2120
TURN OFF EAST RAM RAMAN PUMPS
2125
TURN OFF EAST REM RAMAN PUMPS
2130
MODULATE EAST PILOT LASER TO TRANSMIT RRF SIGNAL
2135
TURN OFF EAST RX AND TX AMPLIFIERS
2140
TRANSMIT BDI SIGNAL ON EAST-TO-WEST LINK
2145
DETECT PILOT RRF SIGNAL AT WEST RAM
2150
TURN OFF WEST RAM RAMAN PUMPS
2155
GENERATE SD SIGNAL
2160
MODULATE WEST PILOT LASER TO TRANSMIT NRM SIGNAL
2165
DETECT BDI SIGNAL AND TURN OFF WEST RX AND TX AMPLIFIERS

FIG. 21

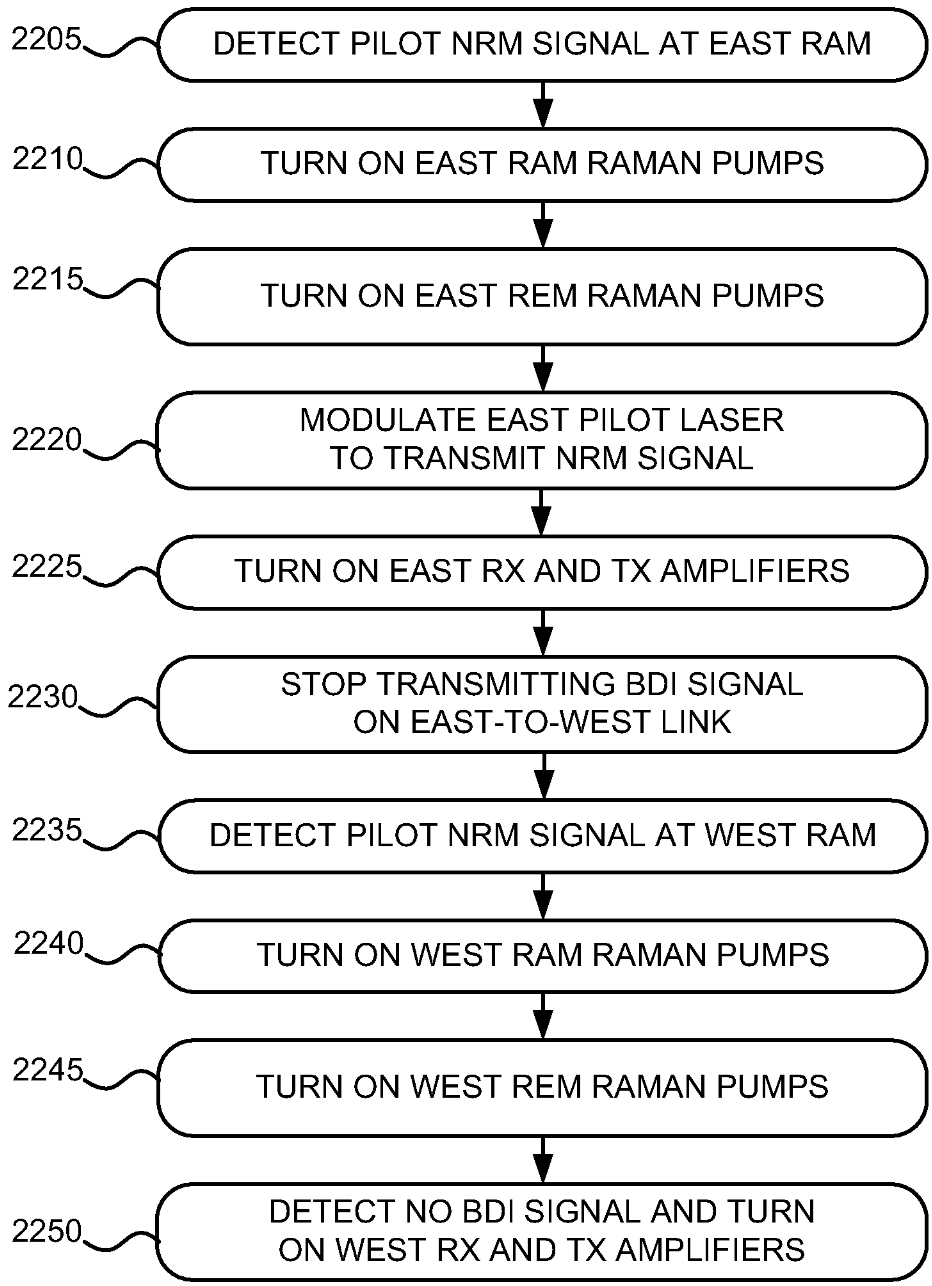

2205
DETECT PILOT NRM SIGNAL AT EAST RAM
2210
TURN ON EAST RAM RAMAN PUMPS
2215
TURN ON EAST REM RAMAN PUMPS
2220
MODULATE EAST PILOT LASER TO TRANSMIT NRM SIGNAL
2225
TURN ON EAST RX AND TX AMPLIFIERS
2230
STOP TRANSMITTING BDI SIGNAL ON EAST-TO-WEST LINK
2235
DETECT PILOT NRM SIGNAL AT WEST RAM
2240
TURN ON WEST RAM RAMAN PUMPS
2245
TURN ON WEST REM RAMAN PUMPS
2250
DETECT NO BDI SIGNAL AND TURN ON WEST RX AND TX AMPLIFIERS

FIG. 22

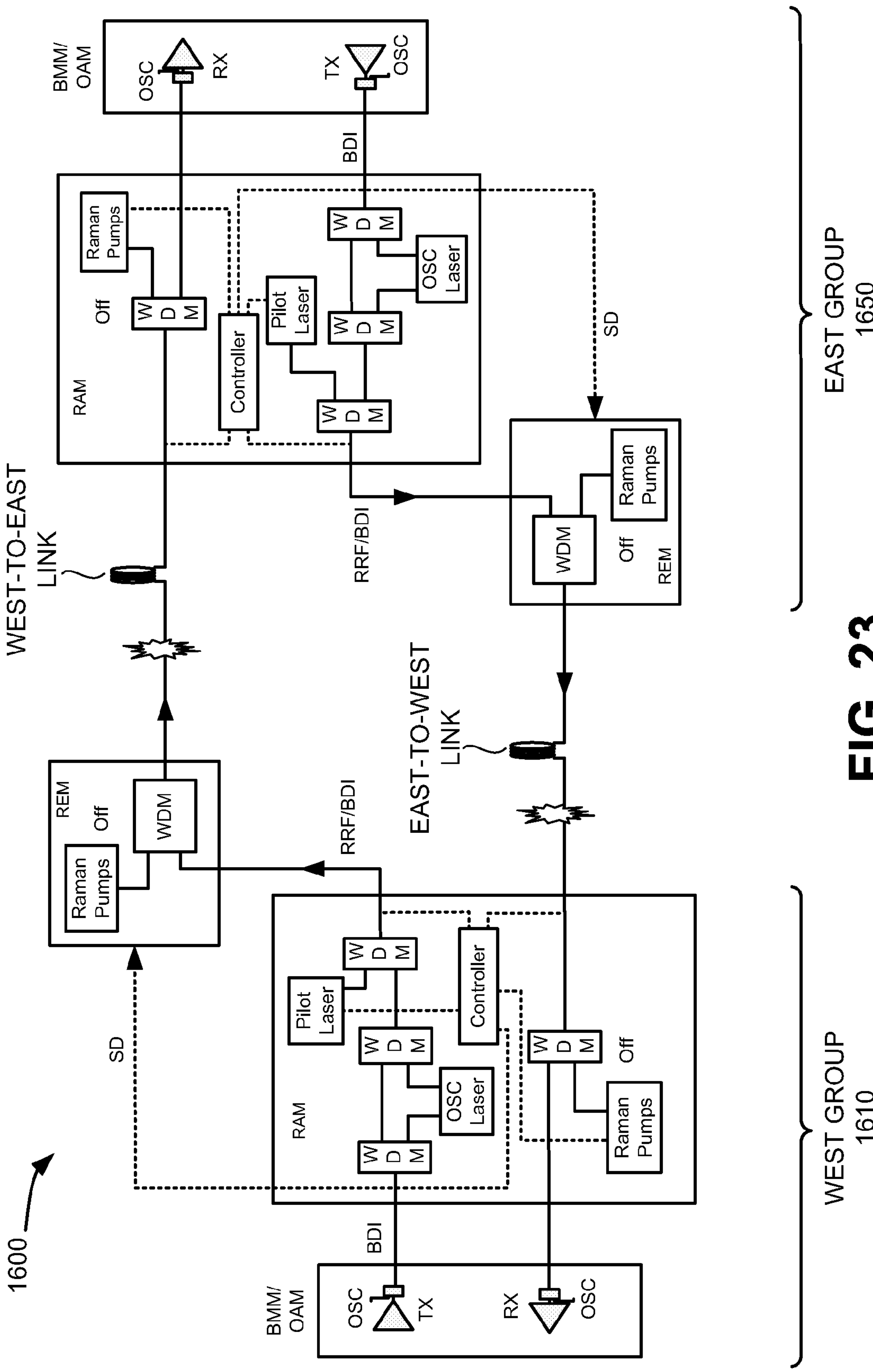

1600
BMM/ OAM
OSC
TX
RX
OSC
BDI
RAM
W D M
Pilot Laser
Controller
OSC Laser
Off
Raman Pumps
SD
REM
WDM
RRF/BDI
WEST-TO-EAST LINK
EAST-TO-WEST LINK
WEST GROUP 1610
EAST GROUP 1650

FIG. 23

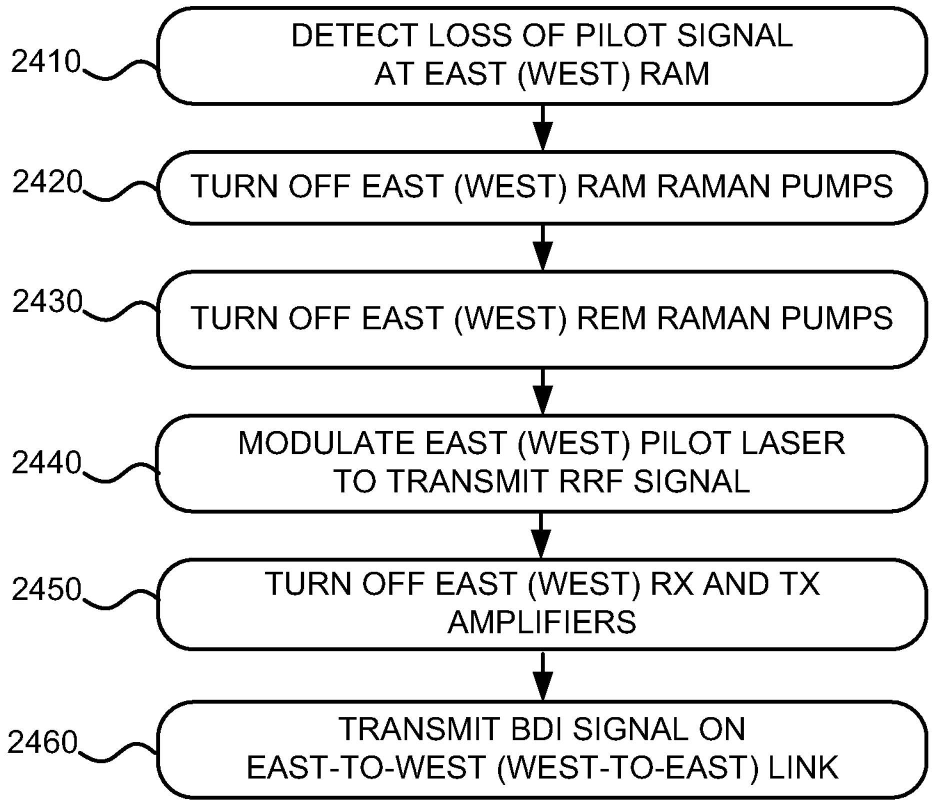

2410
DETECT LOSS OF PILOT SIGNAL AT EAST (WEST) RAM
2420
TURN OFF EAST (WEST) RAM RAMAN PUMPS
2430
TURN OFF EAST (WEST) REM RAMAN PUMPS
2440
MODULATE EAST (WEST) PILOT LASER TO TRANSMIT RRF SIGNAL
2450
TURN OFF EAST (WEST) RX AND TX AMPLIFIERS
2460
TRANSMIT BDI SIGNAL ON EAST-TO-WEST (WEST-TO-EAST) LINK

FIG. 24

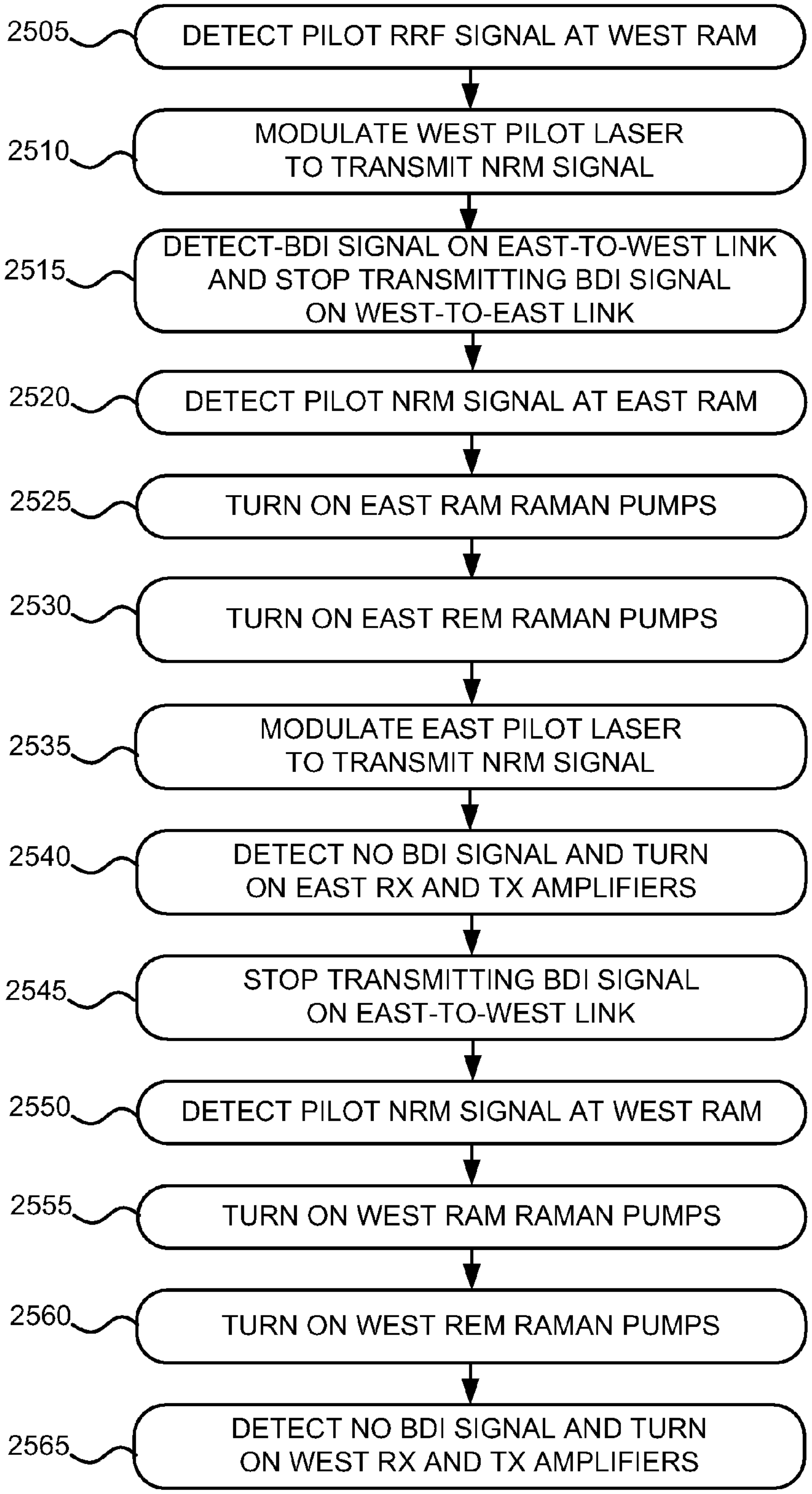

2505
DETECT PILOT RRF SIGNAL AT WEST RAM
2510
MODULATE WEST PILOT LASER TO TRANSMIT NRM SIGNAL
2515
DETECT-BDI SIGNAL ON EAST-TO-WEST LINK AND STOP TRANSMITTING BDI SIGNAL ON WEST-TO-EAST LINK
2520
DETECT PILOT NRM SIGNAL AT EAST RAM
2525
TURN ON EAST RAM RAMAN PUMPS
2530
TURN ON EAST REM RAMAN PUMPS
2535
MODULATE EAST PILOT LASER TO TRANSMIT NRM SIGNAL
2540
DETECT NO BDI SIGNAL AND TURN ON EAST RX AND TX AMPLIFIERS
2545
STOP TRANSMITTING BDI SIGNAL ON EAST-TO-WEST LINK
2550
DETECT PILOT NRM SIGNAL AT WEST RAM
2555
TURN ON WEST RAM RAMAN PUMPS
2560
TURN ON WEST REM RAMAN PUMPS
2565
DETECT NO BDI SIGNAL AND TURN ON WEST RX AND TX AMPLIFIERS

FIG. 25

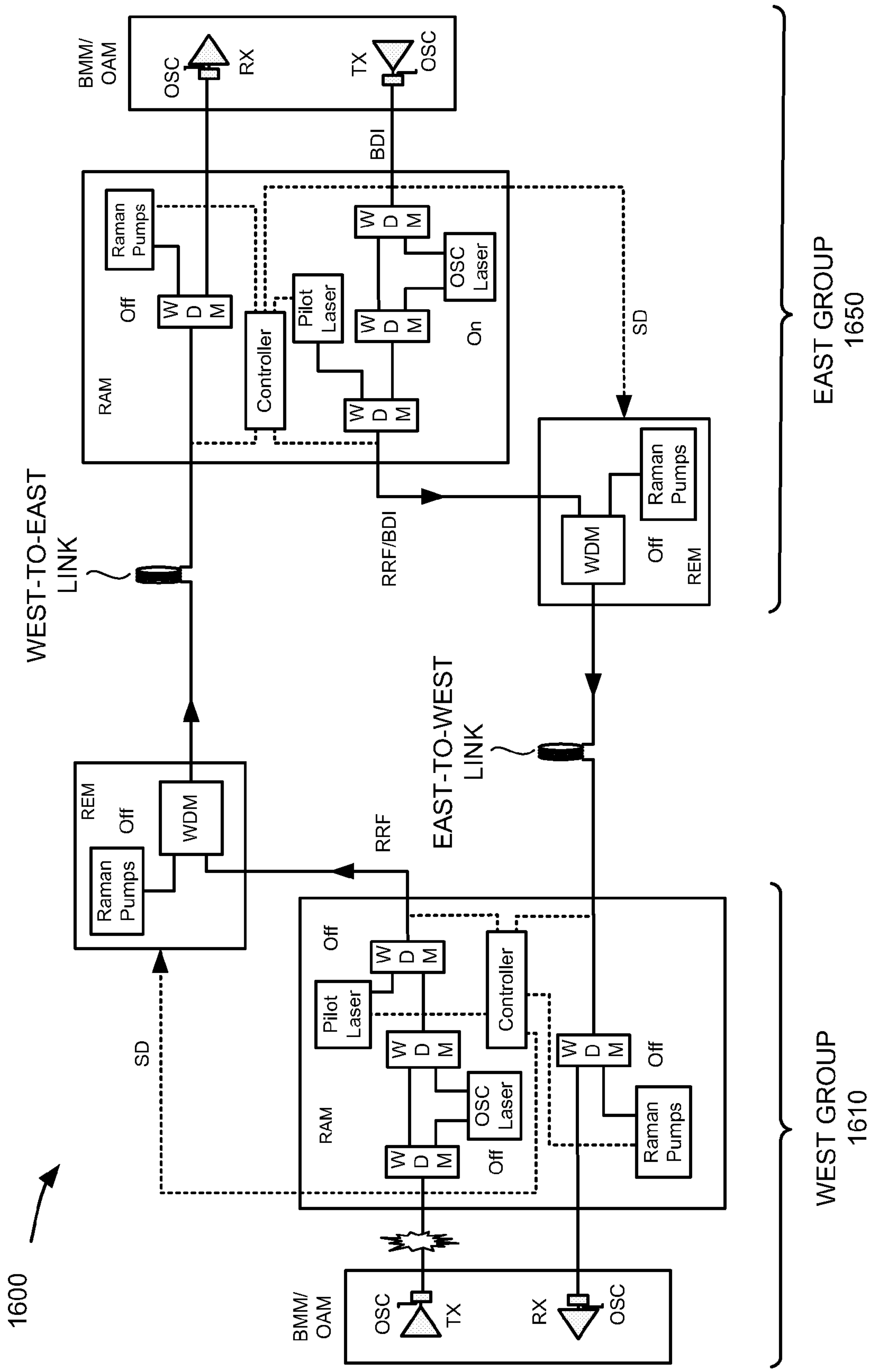

1600
BMM/
OAM
OSC
TX
RX
OSC
RAM
WDM
Pilot
Laser
OSC
Laser
Controller
Raman
Pumps
Off
SD
REM
RRF
WEST-TO-EAST
LINK
EAST-TO-WEST
LINK
RRF/BDI
BDI
On
WEST GROUP
1610
EAST GROUP
1650

FIG. 26

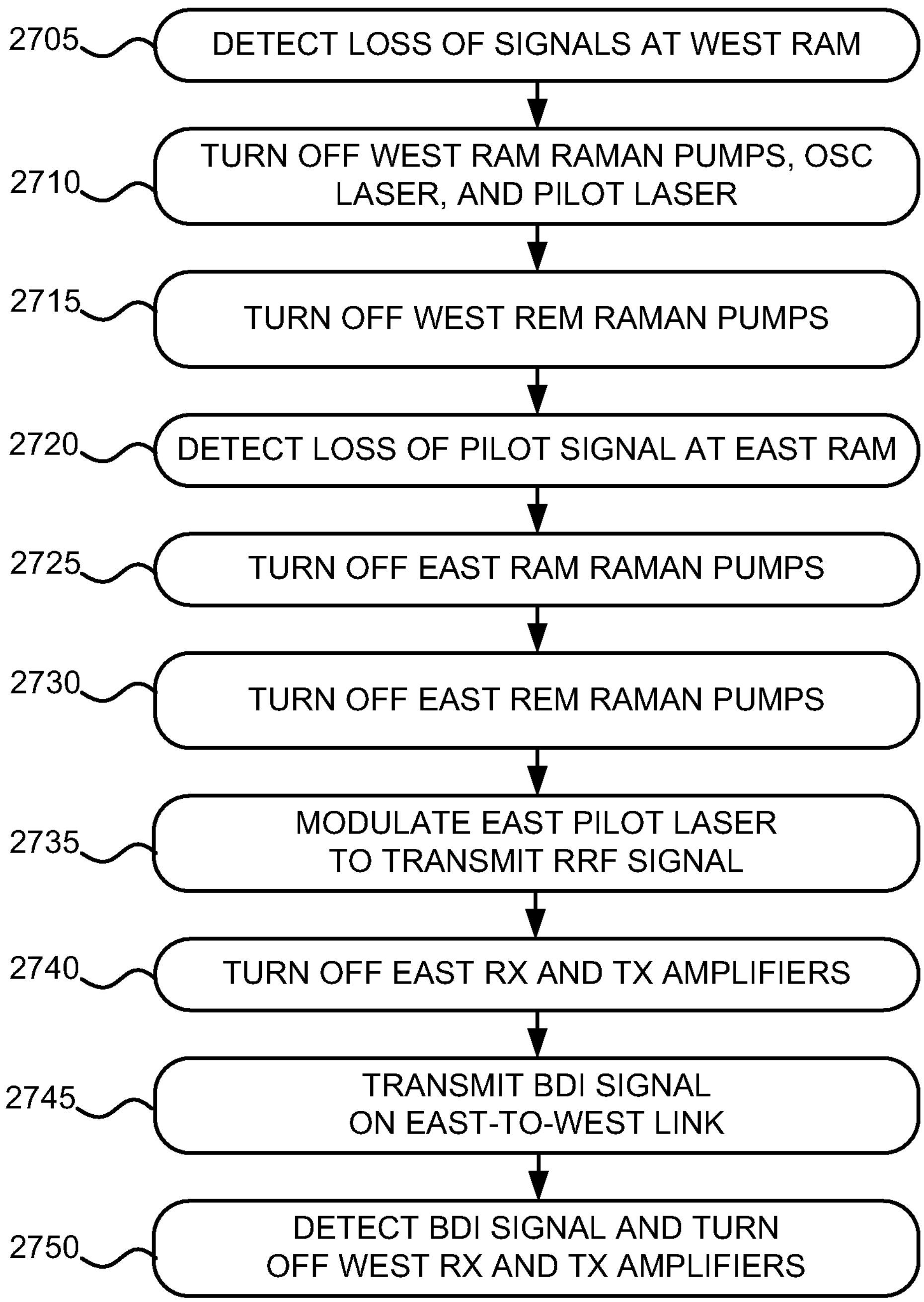
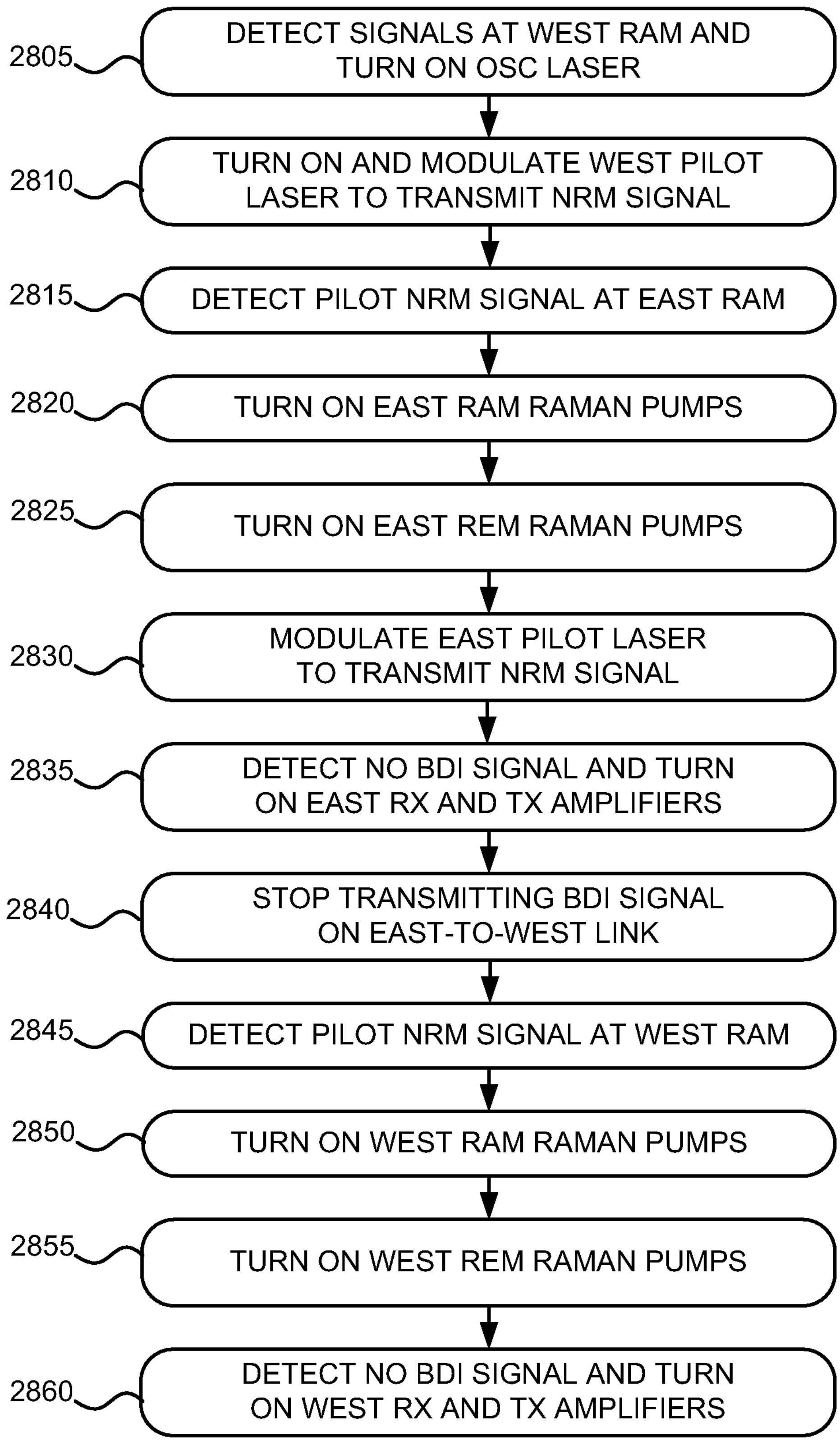

2705
DETECT LOSS OF SIGNALS AT WEST RAM
2710
TURN OFF WEST RAM RAMAN PUMPS, OSC LASER, AND PILOT LASER
2715
TURN OFF WEST REM RAMAN PUMPS
2720
DETECT LOSS OF PILOT SIGNAL AT EAST RAM
2725
TURN OFF EAST RAM RAMAN PUMPS
2730
TURN OFF EAST REM RAMAN PUMPS
2735
MODULATE EAST PILOT LASER TO TRANSMIT RRF SIGNAL
2740
TURN OFF EAST RX AND TX AMPLIFIERS
2745
TRANSMIT BDI SIGNAL ON EAST-TO-WEST LINK
2750
DETECT BDI SIGNAL AND TURN OFF WEST RX AND TX AMPLIFIERS

FIG. 27



2805
DETECT SIGNALS AT WEST RAM AND TURN ON OSC LASER
2810
TURN ON AND MODULATE WEST PILOT LASER TO TRANSMIT NRM SIGNAL
2815
DETECT PILOT NRM SIGNAL AT EAST RAM
2820
TURN ON EAST RAM RAMAN PUMPS
2825
TURN ON EAST REM RAMAN PUMPS
2830
MODULATE EAST PILOT LASER TO TRANSMIT NRM SIGNAL
2835
DETECT NO BDI SIGNAL AND TURN ON EAST RX AND TX AMPLIFIERS
2840
STOP TRANSMITTING BDI SIGNAL ON EAST-TO-WEST LINK
2845
DETECT PILOT NRM SIGNAL AT WEST RAM
2850
TURN ON WEST RAM RAMAN PUMPS
2855
TURN ON WEST REM RAMAN PUMPS
2860
DETECT NO BDI SIGNAL AND TURN ON WEST RX AND TX AMPLIFIERS

FIG. 28

AUTOMATIC LASER SHUTDOWN AND RECOVERY IN RESPONSE TO A LINK BREAK

BACKGROUND

Wavelength-division multiplexing (WDM) is a technique where light signals of different wavelengths are combined and simultaneously transmitted over a single optical fiber. Long distance WDM systems often use amplification to amplify the light signals.

One form of amplification is called Raman amplification. With Raman amplification, the amplification effect is achieved by an interaction between the signal and a pump laser within an optical fiber. One type of Raman amplification is commonly referred to as distributed Raman amplification. Distributed Raman amplification uses the transmission fiber as a gain medium by multiplexing a pump light wavelength with a signal wavelength. The pump light may be coupled into the transmission fiber in the same direction as the signal (co-propagating), in the opposite direction (counter-propagating) as the signal, or both.

SUMMARY

According to one implementation, a communication system may include a first optical source to supply a first optical signal to a first optical link, the first optical signal propagating in a first direction along the first optical link; a second optical source to supply a second optical signal to a second optical link, the second optical signal propagating in the first direction along the second optical link; first control circuit to detect an absence of the first optical signal on the first optical link, and output a first signal in response to detecting the absence of the first optical signal; a third optical source to supply a third optical signal to the second optical link in response to the first signal, the third optical signal propagating in a second direction different than the first direction; a second control circuit to detect a presence of the third optical signal on the second optical link, and output a second signal in response to detecting the presence of the third optical signal; and a fourth optical source supplying a plurality of fourth optical signals to the second optical link, the plurality of fourth optical signals propagating along the second optical link in the second direction, where the second optical source is disabled in response to the second signal, and the second optical signal provides Raman gain to the fourth optical signal.

According to another implementation, a communication system may include a first control circuit to detect a break on a first optical link; a pilot laser to supply a first optical signal on a second optical link in response to detecting the break on the first optical link, the first optical signal propagating in a first direction on the second optical link; a second control circuit to detect a presence of the first optical signal on the second optical link, and output a control signal in response to detecting the presence of the first optical signal; and a Raman pump to supply a second optical signal on the second optical link, the second optical signal propagating in a second direction opposite the first direction, where the Raman pump is disabled in response to the control signal.

According to yet another implementation, a method may include supplying a first optical signal on a first optical link, the first optical signal propagating in a first direction on the first optical link; supplying a second optical signal on the first optical link, the second optical signal propagating in a second direction, that is opposite the first direction, on the first optical link; detecting an absence of the first optical signal on the first optical link; disabling the supplying of the second optical signal on the first optical link in response to detecting the absence of the first optical signal; supplying a third optical signal on a second optical link in response to detecting the absence of the first optical signal, the third optical signal propagating in the second direction on the second optical link; supplying a fourth optical signal on the second optical link, the fourth optical signal propagating in the first direction on the second optical link; detecting a presence of the third optical signal on the second optical link; and disabling the supplying of the fourth optical signal on the second optical link in response to detecting the presence of the third optical signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate one or more implementations described herein and, together with the description, explain these implementations. In the drawings:

FIG. **1** is a diagram of an exemplary system in which systems and/or methods described herein may be implemented;

FIG. **2** is a diagram of exemplary components of a Raman amplifier module (RAM) shown in FIG. **1**;

FIG. **3** is another diagram of exemplary components of a RAM shown in FIG. **1**;

FIG. **4** is a diagram of the exemplary system of FIG. **1** in a situation where a link break occurs on a west-to-east link;

FIG. **5** is a flowchart of an exemplary process for shutting down components in response to the link break of FIG. **4**;

FIG. **6** is a flowchart of an exemplary process for restoring components in response to repair of the link break of FIG. **4**;

FIG. **7** is a diagram of the exemplary system of FIG. **1** in a situation where link breaks occur on both a west-to-east link and an east-to-west link;

FIG. **8** is a flowchart of an exemplary process for shutting down components in response to the link breaks of FIG. **7**;

FIG. **9** is a flowchart of an exemplary process for restoring components in response to repair of the link breaks of FIG. **7**;

FIG. **10** is a diagram of the exemplary system of FIG. **1** in a situation where a link break occurs on a local transmit link;

FIG. **11** is a flowchart of an exemplary process for shutting down components in response to the link break of FIG. **10**;

FIG. **12** is a flowchart of an exemplary process for restoring components in response to repair of the link break of FIG. **10**;

FIG. **13** is a diagram of the exemplary system of FIG. **1** in a situation where a link break occurs on a local receive link;

FIG. **14** is a flowchart of an exemplary process for shutting down components in response to the link break of FIG. **13**;

FIG. **15** is a flowchart of an exemplary process for restoring components in response to repair of the link break of FIG. **13**;

FIG. **16** is a diagram of another exemplary system in which systems and/or methods described herein may be implemented;

FIG. **17** is a diagram of the exemplary system of FIG. **16** in a situation where a link break occurs on a west-to-east link;

FIG. **18** is a flowchart of an exemplary process for shutting down components in response to the link break of FIG. **17**;

FIG. **19** is a flowchart of an exemplary process for restoring components in response to repair of the link break of FIG. **17**;

FIG. **20** is a diagram of the exemplary system of FIG. **16** in a situation where a link break occurs on a local link;

FIG. **21** is a flowchart of an exemplary process for shutting down components in response to the link break of FIG. **20**;

FIG. **22** is a flowchart of an exemplary process for restoring components in response to repair of the link break of FIG. **20**;

FIG. **23** is a diagram of the exemplary system of FIG. **16** in a situation where link breaks occur on both a west-to-east link and an east-to-west link;

FIG. **24** is a flowchart of an exemplary process for shutting down components in response to the link breaks of FIG. **23**;

FIG. **25** is a flowchart of an exemplary process for restoring components in response to repair of the link breaks of FIG. **23**;

FIG. **26** is a diagram of the exemplary system of FIG. **16** in a situation where a link break occurs on a local transmit link;

FIG. **27** is a flowchart of an exemplary process for shutting down components in response to the link break of FIG. **26**; and

FIG. **28** is a flowchart of an exemplary process for restoring components in response to repair of the link break of FIG. **26**.

DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements. Also, the following detailed description does not limit the invention.

Overview

Implementations, described herein, may use counter-propagating and/or co-propagating Raman pumps to perform distributed Raman amplification. Raman pumps may output relatively high power levels (e.g., optical signals with wavelengths in the range of approximately 1420-1460 nanometers (nm)) compared to the power levels of other power-generating components. Due to the relatively high power levels of the Raman pumps, noise associated with the Raman pumps may make it difficult to detect link breaks using a simple power detection of the payload (that may include a number of multiplexed payload channels) and optical supervisory channel (OSC) signal powers. In the description to follow, the payload will be referred to as a "C-band payload" (e.g., optical signals with wavelengths in the range of approximately 1530-1565 nm), though the description is not limited to payload in the C-band. Also, some implementations may not use an OSC signal.

Accordingly, implementations, described herein, may perform fiber break detection using a dedicated pilot laser that transmits a pilot signal (e.g., an optical signal with a wavelength of approximately 1610 nm) that co-propagates with the payload and the OSC signal. The pilot laser may be modulated to produce one of two tone signals that facilitate in the link shutdown and recovery processes:

- Remote Receive Fault (RRF) signal: may be used to notify the far end of the link about a fiber break in the opposite fiber span and to indicate to the far end should turn off (e.g., disable) its pumps.
- Normal (NRM) signal: may be used to notify the far end of the link that no fiber break exists in the opposite fiber span and to indicate that the far end should turn on (e.g., enable) its pumps.

These signals may be designed for ease of detection in high loss links. These signals may be generated at the near end of the link and may be detected and used at the far end of the link.

Exemplary System

FIG. **1** is a diagram of an exemplary system **100** in which systems and/or methods described herein may be implemented. While FIG. **1** shows a particular number and arrangement of components, system **100** may include additional, fewer, different, or differently arranged components than those illustrated in FIG. **1**. As shown in FIG. **1**, system **100** may include a west group of components (hereinafter referred to as "group **110**") and an east group of components (hereinafter referred to as "group **150**") connected by a west-to-east link and an east-to-west link. The west-to-east link and the east-to-west link may include optical fibers. The term "group," as used herein, may refer to a collection of components that may be located at a same end of a fiber.

West group **110** may include a band multiplexer module (BMM)/optical amplifier module (OAM) (hereinafter referred to as BMM/OAM) **112** and Raman amplifier module (RAM) **118**. BMM/OAM **112** may include a transmitter (TX) module **114** and a receiver (RX) module **116**. Transmitter module **114** may generally be referred to as an optical source. In one implementation, transmitter module **114** may include an amplifier (e.g., an Erbium-doped fiber amplifier (EDFA)) that may output a C-band payload (e.g., optical signals with wavelengths in the range of approximately 1530-1565 nm), and an OSC source that may output an OSC signal (e.g., optical signal with wavelengths in the range of approximately 1505-1520 nm). Transmitter module **114** may also include a wavelength-division multiplexer (WDM) that may optically combine the C-band payload and the OSC signal for output from BMM/OAM **112**. Receiver module **116** may generally be referred to as an optical signal detector. In one implementation, receiver module **116** may include an amplifier (e.g., an EDFA) that may receive a C-band payload, and an OSC detector that may receive an OSC signal. Receiver module **116** may also include a wavelength-division demultiplexer (also referred to herein as a WDM) that may receive a combined C-band payload and OSC signal at an input of BMM/OAM **112** and optically separate the C-band payload and the OSC signal for presentation to the amplifier and OSC detector, respectively.

RAM **118** may include components for performing Raman amplification. FIG. **2** is a diagram of exemplary components of RAM **118** according to one implementation. While FIG. **2** shows a particular number and arrangement of components, RAM **118** may include additional, fewer, different, or differently arranged components than are illustrated in FIG. **2**.

As shown in FIG. **2**, RAM **118** may include a pilot laser **210**, a WDM **220**, Raman pumps **230**, another WDM **240**, and a controller **250**. Pilot laser **210** may generally be referred to as an optical source. In one implementation, pilot laser **2120** may include a laser that generates, for example, a 1610 nm pilot signal that may be transmitted to co-propagate with the combined C-band payload and OSC signal. In another implementation, pilot laser **210** may generate a light signal of another wavelength that may be selected so as not to interfere with the C-band payload or OSC signal and that may be detected on the far end of the link in the presence of noise from the Raman pumps (on the far end of the link). Pilot laser **210** may modulate the pilot signal to produce one of two tone signals that facilitate in link shutdown and recovery processes. In one implementation, pilot laser **210** may modulate the pilot signal to produce a remove receive fault (RRF) signal or a normal (NRM) signal. The RRF signal may be used to notify the RAM at the far end of the link (e.g., west-to-east link) that a fiber break has been detected in the opposite link (i.e., east-to-west link). The NRM signal may be used to notify the RAM at the far end of the link that no fiber break has been detected in the opposite link. WDM **220** may include an optical multiplexer that may receive the pilot signal from pilot laser **210** and the combined C-band payload and OSC signal from transmitter module **114** (FIG. **1**) and optically combine them for output on the west-to-east link.

Raman pumps **230** may generally be referred to as an optical source that provides distributed Raman amplification. In one implementation, Raman pumps **230** may include one or more pump lasers that produce pump power (also called pump light) (e.g., optical signals with in the range of approximately 1420-1460 nm) that may be transmitted so as to counter-propagate with the C-band payload, OSC signal, and pilot signal. WDM **240** may include an optical demultiplexer that may receive the combined C-band payload, OSC signal, and pilot signal from the east-to-west link and optically separate the C-band payload and OSC signal for output to receiver module **116** (FIG. **1**). WDM **240** may also receive the pump power from Raman pumps **230** and output the pump power on the east-to-west link.

Controller **250** may include a control circuit, such as a field programmable gate array (FPGA), or another type of hardware, that may detect the pilot signals transmitted on west-to-east link and/or east-to-west link. Controller **250** may control the operation of pilot laser **210** to turn on or off and/or to produce the RRF signal or the NRM signal. Controller **250** may also control the operation of Raman pumps **230** to turn on or off.

FIG. **3** is another diagram of exemplary components of RAM **118** according to another implementation. While FIG. **3** shows a particular number and arrangement of components, RAM **118** may include additional, fewer, different, or differently arranged components than are illustrated in FIG. **3**.

As shown in FIG. **3**, RAM **118** may include a WDM **310**, an OSC laser **320**, a WDM **330**, a pilot laser **340**, a WDM **350**, Raman pumps **360**, a WDM **370**, and a controller **380**. WDM **310** may include an optical demultiplexer that may receive the combined C-band payload and OSC signal from transmitter module **114** (FIG. **1**) and optically separate the C-band payload from the OSC signal. WDM **310** may provide the C-band payload to WDM **330** and the OSC signal to OSC laser **320**. OSC laser **320** may generally be referred to as an optical source. In one implementation, OSC laser **320** may include a regeneration laser that may receive the OSC signal and regenerate the OSC signal for output to WDM **330**. WDM **330** may include an optical multiplexer that may receive the C-band payload and the regenerated OSC signal, optically combine them, and output a combined C-band payload and OSC signal to WDM **350**.

Pilot laser **340** may generally be referred to as an optical source. In one implementation, pilot laser **340** may include a laser that generates, for example, a 1610 nm pilot signal that may be transmitted to co-propagate with the combined C-band payload and OSC signal. In another implementation, pilot laser **210** may generate a light signal of another wavelength that may be selected so as not to interfere with the C-band payload or OSC signal and that may be detected on the far end of the link in the presence of noise from the Raman pumps (on the far end of the link). Pilot laser **340** may modulate the pilot signal to produce one of two tone signals that facilitate in link shutdown and restoration processes. In one implementation, pilot laser **340** may modulate the pilot signal to produce a RRF signal or a NRM signal. As explained above, the RRF signal may be used to notify the RAM at the far end of the link (e.g., west-to-east link) that a fiber break has been detected in the opposite link (i.e., east-to-west link). As also explained above, the NRM signal may be used to notify the RAM at the far end of the link that no fiber break has been detected in the opposite link. WDM **350** may include an optical multiplexer that may receive the pilot signal from pilot laser **340** and the combined C-band payload and OSC signal from WDM **330** and optically combine them for output on the west-to-east link.

Raman pumps **360** may generally be referred to as an optical source that provides distributed Raman amplification. In one implementation, Raman pumps **360** may include one or more pump lasers that produce pump power (also called pump light) (e.g., optical signals with in the range of approximately 1420-1460 nm) that may be transmitted so as to counter-propagate with the C-band payload, OSC signal, and pilot signal. WDM **370** may include an optical demultiplexer that may receive the combined C-band payload, OSC signal, and pilot signal from the east-to-west link and optically separate the C-band payload and OSC signal for output to receiver module **116** (FIG. **1**). WDM **370** may also receive the pump power from Raman pumps **360** and output the pump power on the east-to-west link.

Controller **380** may include a control circuit, such as a FPGA, or another type of hardware, that may detect the pilot signals transmitted on west-to-east link and/or east-to-west link. Controller **380** may control the operation of pilot laser **340** to turn on or off and/or to produce the RRF signal or the NRM signal. Controller **380** may also control the operation of Raman pumps **360** to turn on or off. Controller **380** may further control the operation of OSC laser **320** to turn on or off (not shown in FIG. **3**).

Returning to FIG. **1**, east group **150** may include a BMM/OAM **152** and Raman amplifier module (RAM) **158**. BMM/OAM **152** may include a transmitter (TX) module **154** and a receiver (RX) module **156**. Transmitter module **154** and receiver module **156** may be similar in construction and operation to transmitter module **114** and receiver module **116** described with regard to west group **110**. RAM **158** may be similar in construction and operation to RAM **118** described with regard to west group **110**.

Link Break on West-to-East Link

During normal operation (prior to the link break) (e.g., FIG. **1**), west group **110** and east group **150** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **110** may transmit signals to east group **150** on the west-to-east link, and east group **150** may transmit signals to west group **110** on the east-to-west link. During this time, pilot laser **210**/**340** may be turned on and may output a pilot NRM signal, and Raman pumps **230**/**360** may be turned on and may output pump power.

Now assume that a link break occurs on the west-to-east link. FIG. **4** is a diagram of exemplary system **100** in the situation where a link break occurs on the west-to-east link. FIG. **5** is a flowchart of an exemplary process for shutting down components in response to the link break. In the description to follow, reference will be made to certain components of west group **110** and east group **150**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **110** will be referred to as the west RAM, and the RAM in east group **150** will be referred to as the east RAM.

The loss of the pilot signal may be detected at the east RAM (block **510**). For example, due to the link break, the pilot signal outputted by the west RAM cannot reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal. Because the pilot signal is generated at 1610 nm, the east controller can differentiate the presence or absence of the pilot signal even in the presence of noise generated by the east Raman pumps, which may be in the range of approximately 1420-1460 nm.

The east Raman pumps may be turned off (block **520**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal for the east Raman pumps to turn off. The east Raman pumps may turn off in response to the signal from the east controller, as shown in FIG. **4**.

The east pilot laser may be modulated to transmit the RRF signal (block **530**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east pilot laser to modulate with the RRF signal. The east pilot laser may modulate with the RRF signal in response to the signal from the east controller, as shown in FIG. **4**.

The amplifiers of the east receiver and transmitter modules may be turned off (block **540**). The east receiver module may detect the loss of the C-band payload and/or OSC signal, as a result of the link break, and may turn off its amplifier. When the east receiver module turns off its amplifier, it may trigger the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier.

A backward defect indication (BDI) signal may be transmitted on the east-to-west link (block **550**). For example, when the east transmitter module turns off its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to generate the BDI signal and output the BDI signal to the east WDM. The east WDM may optically combine the BDI signal with the pilot RRF signal and output the combined BDI signal and RRF signal on the east-to-west link.

The pilot RRF signal may be detected at the west RAM (block **560**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller may detect the presence of the RRF signal.

The west Raman pumps may be turned off (block **570**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may send a signal for the west Raman pumps to turn off. The west Raman pumps may turn off in response to the signal from the west controller, as shown in FIG. **4**.

The west pilot laser may be modulated to transmit the NRM signal (block **580**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may send a signal to the west pilot laser to modulate with the NRM signal. The west pilot laser may modulate with the NRM signal in response to the signal from the west controller, as shown in FIG. **4**. The NRM signal may indicate to the east RAM that the east-to-west link is operable.

The BDI signal may be detected and the amplifiers of the west receiver and transmitter modules may be turned off (block **590**). For example, the west receiver module may detect the BDI signal from the east transmitter module, and turn off its amplifier. When the west receiver module turns off its amplifier, it triggers the west transmitter module to turn off its amplifier. The west transmitter module may then turn off its amplifier. Both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link break.

FIG. **6** is a flowchart of an exemplary process for restoring components in response to repair of the link break. The pilot NRM signal may be detected at the east RAM (block **610**). For example, now that the link break has been repaired, the pilot NRM signal outputted by the west RAM can reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal and detect the NRM signal.

The east Raman pumps may be turned on (block **620**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal for the east Raman pumps to turn on. The east Raman pumps may turn on in response to the signal from the east controller.

The east pilot laser may be modulated to transmit the NRM signal (block **630**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east pilot laser to modulate with the NRM signal. The east pilot laser may modulate with the NRM signal in response to the signal from the east controller.

The amplifiers of the east receiver and transmitter modules may be turned on (block **640**). The east receiver module may detect the C-band payload and/or OSC signal, as a result of the link break being repaired, detect no BDI signal, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier.

The BDI may no longer be transmitted on the east-to-west link (block **650**). For example, when the east transmitter module turns on its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to stop generating the BDI signal.

The pilot NRM signal may be detected at the west RAM (block **660**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the NRM signal.

The west Raman pumps may be turned on (block **670**). For example, when the west controller detects the pilot NRM signal from the east RAM, the west controller may send a signal to the west Raman pumps to turn on. The west Raman pumps may turn on in response to the signal from the west controller.

No BDI signal may be detected on the east-to-west link, and the amplifiers of the west receiver and transmitter modules may be turned on (block **590**). For example, the west receiver module may detect the removal of the BDI signal from the east transmitter module, and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier. As a result, system **100** may return to normal operation.

Link Breaks on Both West-to-East Link and East-to-West Link

During normal operation (prior to the link break) (e.g., FIG. **1**), west group **110** and east group **150** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **110** may transmit signals to east group **150** on the west-to-east link, and east group **150** may transmit signals to west group **110** on the east-to-west link. During this time, pilot laser **210**/**340** may be turned on and may output a pilot NRM signal, and Raman pumps **230**/**360** may be turned on and may output pump power.

Now assume that link breaks occur on both the west-to-east link and the east-to-west link. FIG. **7** is a diagram of exemplary system **100** in the situation where link breaks occur on both the west-to-east link and the east-to-west link. FIG. **8** is a flowchart of an exemplary process for shutting down components in response to the link breaks. In the description to follow, reference will be made to certain components of west group **110** and east group **150**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **110** will be referred to as the west RAM, and the RAM in east group **150** will be referred to as the east RAM.

The loss of the pilot signal may be detected at the east RAM (block **810**). For example, due to the link break, the pilot signal outputted by the west RAM cannot reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal. Because the pilot signal is generated at 1610 nm, the east controller can differentiate the presence or absence of the pilot signal even in the presence of noise generated by the east Raman pumps, which may be in the range of approximately 1420-1460 nm.

The east Raman pumps may be turned off (block **820**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east Raman pumps to turn off. The east Raman pumps may turn off in response to the signal from the east controller, as shown in FIG. **7**.

The east pilot laser may be modulated to transmit the RRF signal (block **830**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east pilot laser to modulate with the RRF signal. The east pilot laser may modulate with the RRF signal in response to the signal from the east controller, as shown in FIG. **7**.

The amplifiers of the east receiver and transmitter modules may be turned off (block **840**). The east receiver module may detect the loss of the C-band payload and/or OSC signal, as a result of the link break, and turn off its amplifier. When the east receiver module turns off its amplifier, it triggers the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier.

A BDI signal may be transmitted on the east-to-west link (block **850**). For example, the east OSC source, associated with the east transmitter module, may generate the BDI signal and output the BDI signal to the east WDM. The east WDM may optically combine the BDI signal with the pilot RRF signal and output the combined BDI signal and RRF signal on the east-to-west link. The combined BDI signal and RRF signal will not arrive at west group **110** due to the link break on the east-to-west link.

Simultaneously, or substantially simultaneously, blocks **810-850** may be performed by west group **110**. As a result, both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link breaks.

FIG. **9** is a flowchart of an exemplary process for restoring components in response to repair of the link breaks. Assume, for example, that the east-to-west link is repaired first. The pilot RRF signal may be detected at the west RAM (block **905**). For example, now that the link break on the east-to-west link has been repaired, the pilot RRF signal outputted by the east RAM can reach the west RAM. The west controller (within the west RAM) may monitor the presence of the pilot signal and detect the RRF signal. In response to the pilot RRF signal, the west controller may keep the west Raman pumps turned off.

The west pilot laser may be modulated to transmit the NRM signal (block **910**). For example, the west controller may send a signal to the west pilot laser to modulate with the NRM signal. The west pilot laser may modulate with the NRM signal in response to the signal from the west controller.

The BDI signal may be detected on the east-to-west link and the transmitting of the BDI signal on the west-to-east link may be stopped (block **915**). For example, the west receiver module may detect the restoration of the OSC power and detect the BDI signal sent from east group **150**. The west receiver module may keep its amplifier turned off and signal the west transmitter module to stop transmitting the BDI signal.

When the west-to-east link is repaired, the pilot NRM signal may be detected at the east RAM (block **920**). For example, now that the link break on the west-to-east link has been repaired, the pilot NRM signal outputted by the west RAM can reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal and detect the NRM signal.

The east Raman pumps may be turned on (block **925**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east Raman pumps to turn on. The east Raman pumps may turn on in response to the signal from the east controller.

The east pilot laser may be modulated to transmit the NRM signal (block **930**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east pilot laser to modulate with the NRM signal. The east pilot laser may modulate with the NRM signal in response to the signal from the east controller.

The amplifiers of the east receiver and transmitter modules may be turned on (block **935**). The east receiver module may detect that the OSC power is restored on the west-to-east link, as a result of the link break being repaired, detect no BDI signal, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier.

The BDI may no longer be transmitted on the east-to-west link (block **940**). For example, when the east transmitter module turns on its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to stop generating the BDI signal.

The pilot NRM signal may be detected at the west RAM (block **945**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the NRM signal.

The west Raman pumps may be turned on (block **950**). For example, when the west controller detects the pilot NRM signal from the east RAM, the west controller may send a signal to the west Raman pumps to turn on. The west Raman pumps may turn on in response to the signal from the west controller.

No BDI signal may be detected on the east-to-west link, and the amplifiers of the west receiver and transmitter modules may be turned on (block **955**). For example, the west receiver module may detect the removal of the BDI signal from the east transmitter module, and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier. As a result, system **100** may return to normal operation.

Link Break on Local Transmit Link

During normal operation (prior to the link break) (e.g., FIG. **1**), west group **110** and east group **150** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **110** may transmit signals to east group **150** on the west-to-east link, and east group **150** may transmit signals to west group **110** on the east-to-west link. During this time, pilot laser **210/340** may be turned on and may output a pilot NRM signal, and Raman pumps **230/360** may be turned on and may output pump power.

Now assume that a link break occurs on the local transmit link located between the west BMM/OAM and the west RAM. FIG. **10** is a diagram of exemplary system **100** in the situation where a link break occurs on the local transmit link. FIG. **11** is a flowchart of an exemplary process for shutting down components in response to the link break. In the description to follow, reference will be made to certain components of west group **110** and east group **150**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **110** will be referred to as the west RAM, and the RAM in east group **150** will be referred to as the east RAM.

A loss of C-band payload and/or OSC signal may be detected at the west RAM (block **1110**). For example, due to the link break, the C-band payload and OSC signal outputted by the west BMM/OAM cannot reach the west RAM. The west controller (within the west RAM) may detect the absence of the C-band payload and/or OSC signal.

The west Raman pumps and the west pilot laser may be turned off (block **1120**). For example, when the west controller detects the loss of the C-band payload and/or OSC signal, the west controller may send signals to the west Raman pumps and the west pilot laser to turn off. The west Raman pumps and the west pilot laser may turn off in response to the signals from the west controller, as shown in FIG. **10**. In the situation where the west RAM includes an OSC laser (e.g., OSC laser **320** in FIG. **3**), the west controller may also turn off the west OSC laser at this time.

The loss of the pilot signal may be detected at the east RAM (block **1130**). For example, since the west pilot laser has been turned off, there is no pilot signal to reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal. Because the pilot signal is generated at 1610 nm, the east controller can differentiate the presence or absence of the pilot signal even in the presence of noise generated by the east Raman pumps, which may be in the range of approximately 1420-1460 nm.

The east Raman pumps may be turned off (block **1140**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east Raman pumps to turn off. The east Raman pumps may turn off in response to the signal from the east controller, as shown in FIG. **10**.

The east pilot laser may be modulated to transmit the RRF signal (block **1150**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east pilot laser to modulate with the RRF signal. The east pilot laser may modulate with the RRF signal in response to the signal from the east controller, as shown in FIG. **10**.

The amplifiers of the east receiver and transmitter modules may be turned off (block **1160**). The east receiver module may detect the loss of the C-band payload and/or OSC signal and turn off its amplifier. When the east receiver module turns off its amplifier, it triggers the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier.

A BDI signal may be transmitted on the east-to-west link (block **1170**). For example, when the east transmitter module turns off its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to generate the BDI signal and output the BDI signal to the east WDM. The east WDM may optically combine the BDI signal with the pilot RRF signal and output the combined BDI signal and RRF signal on the east-to-west link, as shown in FIG. **10**.

The BDI signal may be detected and the amplifiers of the west receiver and transmitter modules may be turned off (block **1180**). For example, the west receiver module may detect the BDI signal from the east transmitter module, and turn off its amplifier. When the west receiver module turns off its amplifier, it triggers the west transmitter module to turn off its amplifier. The west transmitter module may then turn off its amplifier. Both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link break.

FIG. **12** is a flowchart of an exemplary process for restoring components in response to repair of the link break. A C-band payload and/or OSC signal may be detected at the west RAM (block **1205**). For example, due to repair of the link break, the C-band payload and OSC signal outputted by the west BMM/OAM can now reach the west RAM. The west controller (within the west RAM) may detect the restoration of the C-band payload and/or OSC signal. In the situation where the west RAM includes an OSC laser (e.g., OSC laser **320** in FIG. **3**), the west controller may also turn on the west OSC laser at this time.

The west pilot laser may be turned on and modulated to transmit the NRM signal (block **1210**). For example, the west controller may detect the pilot RRF signal from the east RAM. In response, the west controller may send a signal to the west pilot laser to turn on and modulate with the NRM signal. The west Raman pumps may remain turned off.

The pilot NRM signal may be detected at the east RAM (block **1215**). For example, now that the west pilot laser has been turned on, the pilot NRM signal outputted by the west RAM can be received by the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal and detect the NRM signal.

The east Raman pumps may be turned on (block **1220**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east Raman pumps to turn on. The east Raman pumps may turn on in response to the signal from the east controller.

The east pilot laser may be modulated to transmit the NRM signal (block **1225**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east pilot laser to modulate with the NRM signal. The east pilot laser may modulate with the NRM signal in response to the signal from the east controller.

The amplifiers of the east receiver and transmitter modules may be turned on (block **1230**). The east receiver module may detect the C-band payload and/or OSC signal, as a result of the link break being repaired, detect no BDI signal, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier.

The BDI may no longer be transmitted on the east-to-west link (block **1235**). For example, when the east transmitter module turns on its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to stop generating the BDI signal.

The pilot NRM signal may be detected at the west RAM (block **1240**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the NRM signal.

The west Raman pumps may be turned on (block **1245**). For example, when the west controller detects the pilot NRM signal from the east RAM, the west controller may send a signal to the west Raman pumps to turn on. The west Raman pumps may turn on in response to the signal from the west controller.

No BDI signal may be detected on the east-to-west link, and the amplifiers of the west receiver and transmitter modules may be turned on (block **1250**). For example, the west receiver module may detect the removal of the BDI signal from the east transmitter module, and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier. As a result, system **100** may return to normal operation.

Link Break on Local Receive Link

During normal operation (prior to the link break) (e.g., FIG. **1**), west group **110** and east group **150** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **110** may transmit signals to east group **150** on the west-to-east link, and east group **150** may transmit signals to west group **110** on the east-to-west link. During this time, pilot laser **210/340** may be turned on and may output a pilot NRM signal, and Raman pumps **230/360** may be turned on and may output pump power.

Now assume that a link break occurs on the local receive link located between the west BMM/OAM and the west RAM. FIG. **13** is a diagram of exemplary system **100** in the situation where a link break occurs on the local receive link. FIG. **14** is a flowchart of an exemplary process for shutting down components in response to the link break. In the description to follow, reference will be made to certain components of west group **110** and east group **150**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **110** will be referred to as the west RAM, and the RAM in east group **150** will be referred to as the east RAM.

A loss of C-band payload and/or OSC signal may be detected at the west BMM/OAM (block **1410**). For example, due to the link break, the C-band payload and OSC signal outputted by the east BMM/OAM cannot reach the west BMM/OAM. The west receiver module may detect this loss of the C-band payload and the OSC signal.

The amplifiers of the west receiver and transmitter modules may be turned off (block **1420**). For example, the west receiver module may detect the loss of the C-band payload and/or OSC signal and turn off its amplifier. When the west receiver module turns off its amplifier, it triggers the west transmitter module to turn off its amplifier. The west transmitter module may then turn off its amplifier.

A BDI signal may be transmitted on the west-to-east link (block **1430**). For example, when the west transmitter module turns off its amplifier, the west transmitter module may trigger the west OSC source, associated with the west transmitter module, to generate the BDI signal and output the BDI signal for transmission on the west-to-east link.

The BDI signal may be detected and the amplifiers of the east receiver and transmitter modules may be turned off (block **1440**). For example, the east receiver module may detect the BDI signal from the west transmitter module, and turn off its amplifier. When the east receiver module turns off its amplifier, it triggers the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier. Both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link break.

FIG. **15** is a flowchart of an exemplary process for restoring components in response to repair of the link break. A C-band payload and/or OSC signal, and no BDI signal, may be detected at the west BMM/OAM (block **1510**). For example, due to repair of the link break, the C-band payload and OSC signal outputted by the east BMM/OAM can now reach the west BMM/OAM. The west receiver module may detect this restoration of the C-band payload and the OSC signal.

The amplifiers of the west receiver and transmitter modules may be turned on (block **1520**). For example, the west receiver module may detect the restoration of the C-band payload and/or OSC signal and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier.

Transmission of the BDI signal may be stopped on the west-to-east link (block **1530**). For example, when the west transmitter module turns on its amplifier, the west transmitter module may trigger the west OSC source, associated with the west transmitter module, to stop generating the BDI signal.

No BDI signal may be detected at the east BMM/OAM, and the amplifiers of the east receiver and transmitter modules may be turned on (block **1540**). For example, the east receiver module may detect that the BDI signal from the west transmitter module has been terminated, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier. As a result, system **100** may return to normal operation.

Alternative Exemplary System

FIG. **16** is a diagram of an exemplary system **1600** in which systems and/or methods described herein may be implemented. While FIG. **16** shows a particular number and arrangement of components, system **1600** may include additional, fewer, different, or differently arranged components than those illustrated in FIG. **16**. As shown in FIG. **16**, system **1600** may include a west group of components (hereinafter referred to as "west group **1610**") and an east group of components (hereinafter referred to as "east group **1650**") connected by a west-to-east link and an east-to-west link. The west-to-east link and the east-to-west link may include optical fibers.

West group **1610** may include a BMM/OAM **1612**, a RAM **1620**, and a Raman extender module (REM) **1630**. BMM/OAM **1612** may include a transmitter (TX) module **1614** and a receiver (RX) module **1616**. Transmitter module **1614** may generally be referred to as an optical source. In one implementation, transmitter module **1614** may include an amplifier (e.g., an EDFA) that may output a C-band payload (e.g., optical signals with in the range of approximately 1530-1565 nm), and an OSC source that may output an OSC signal (e.g., optical signal with in the range of approximately 1505-1520 nm). Transmitter module **1614** may also include a WDM that may optically combine the C-band payload and the OSC signal for output from BMM/OAM **1612**. Receiver module **1616** may generally be referred to as an optical signal detector. In one implementation, receiver module **1616** may include an amplifier (e.g., an EDFA) that may receive a C-band payload, and an OSC detector that may receive an OSC signal. Receiver module **1616** may also include a WDM that may receive a combined C-band payload and OSC signal at an input of BMM/OAM **1612** and optically separate the C-band payload and the OSC signal for presentation to the amplifier and OSC detector, respectively.

RAM **1620** may include components for performing Raman amplification. RAM **1620** may include components similar to the components of RAM **118** shown in FIG. **2** or FIG. **3**. RAM **1620** differs from RAM **118**, however, in that the controller of RAM **1620** generates an additional signal that was not generated by the controller of RAM **118**. The controller of RAM **1620** generates a shutdown (SD) signal that the controller may output to REM **1630**, as described below. In one implementation, the SD signal may include a signal line that can be asserted or de-asserted to cause certain operations to be performed by REM **1630**. In this case, generating the SD signal may refer to asserting (or de-asserting) the signal line.

REM **1630** may perform Raman amplification by launching pump power in the same direction as the C-band payload. As shown in FIG. **16**, REM **1630** may include Raman pumps **1632** and WDM **1634**. Raman pumps **1632** may generally be referred to as an optical source that provides distributed amplification. In one implementation, Raman pumps **1632** may include one or more pump lasers that produce pump power (also called pump light) (e.g., optical signals with in the range of approximately 1420-1460 nm) that may be transmitted so as to co-propagate with the C-band payload, OSC signal, and pilot signal. WDM **1634** may include an optical multiplexer that may receive the combined C-band payload, OSC signal, and pilot signal from RAM **1620** and optically combine the combined C-band payload, OSC signal, and pilot signal with the pump power from Raman pumps **1632** for output on the west-to-east link.

East group **1650** may include a BMM/OAM **1652**, a RAM **1660**, and a REM **1670**. BMM/OAM **1652** may include a transmitter (TX) module **1654** and a receiver (RX) module **1656**. Transmitter module **1654** and receiver module **1656** may be similar in construction and operation to transmitter module **1614** and receiver module **1616**, respectively, described with regard to west group **1610**. RAM **1660** may be similar in construction and operation to RAM **1620** described with regard to west group **1610**. REM **1670** may include Raman pumps **1672** and WDM **1674**. Raman pumps **1672** and WDM **1674** may be similar in construction and operation to Raman pumps **1632** and WDM **1634** described with regard to west group **1610**.

Link Break on West-to-East Link

During normal operation (prior to the link break) (e.g., FIG. **16**), west group **1610** and east group **1650** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **1610** may transmit signals to east group **1650** on the west-to-east link, and east group **1650** may transmit signals to west group **1610** on the east-to-west link. During this time, pilot laser **210/340** may be turned on and may output a pilot NRM signal, and Raman pumps **230/360/1632/1670** may be turned on and may output pump power.

Now assume that a link break occurs on the west-to-east link. FIG. **17** is a diagram of exemplary system **1600** in the situation where a link break occurs on the west-to-east link. FIG. **18** is a flowchart of an exemplary process for shutting down components in response to the link break. In the description to follow, reference will be made to certain components of west group **1610** and east group **1650**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **1610** will be referred to as the west RAM, and the RAM in east group **1650** will be referred to as the east RAM.

The loss of the pilot signal may be detected at the east RAM (block **1805**). For example, due to the link break, the pilot signal outputted by the west RAM cannot reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal. Because the pilot signal is generated at 1610 nm, the east controller can differentiate the presence or absence of the pilot signal even in the presence of noise generated by the east Raman pumps, which may be in the range of approximately 1420-1460 nm.

The east RAM Raman pumps may be turned off (block **1810**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east RAM Raman pumps to turn off. The east RAM Raman pumps may turn off in response to the signal from the east controller, as shown in FIG. **17**.

The east REM Raman pumps may be turned off (block **1815**). For example, when the east controller detects the loss of the pilot signal, the east controller may generate the SD signal and send the SD signal to the east REM Raman pumps. The east REM Raman pumps may turn off in response to the SD signal from the east controller, as shown in FIG. **17**.

The east pilot laser may be modulated to transmit the RRF signal (block **1820**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east pilot laser to modulate with the RRF signal. The east pilot laser may modulate with the RRF signal in response to the signal from the east controller, as shown in FIG. **17**.

The amplifiers of the east receiver and transmitter modules may be turned off (block **1825**). The east receiver module may detect the loss of the C-band payload and/or OSC signal, as a result of the link break, and turn off its amplifier. When the east receiver module turns off its amplifier, it triggers the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier.

A BDI signal may be transmitted on the east-to-west link (block **1830**). For example, when the east transmitter module turns off its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to generate the BDI signal and output the BDI signal to be optically combined with the pilot RRF signal and output on the east-to-west link.

The pilot RRF signal may be detected at the west RAM (block **1835**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the RRF signal.

The west RAM Raman pumps may be turned off (block **1840**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may send a signal to the west RAM Raman pumps to turn off. The west RAM Raman pumps may turn off in response to the signal from the west controller, as shown in FIG. **17**.

The west REM Raman pumps may be turned off (block **1845**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may generate the SD signal and send the SD signal to the west REM Raman pumps. The west REM Raman pumps may turn off in response to the SD signal from the west controller, as shown in FIG. **17**.

The west pilot laser may be modulated to transmit the NRM signal (block **1850**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may send a signal to the west pilot laser to modulate with the NRM signal. The west pilot laser may modulate with the NRM signal in response to the signal from the west controller, as shown in FIG. **17**.

The BDI signal may be detected and the amplifiers of the west receiver and transmitter modules may be turned off (block **1855**). For example, the west receiver module may detect the BDI signal from the east transmitter module, and turn off its amplifier. When the west receiver module turns off its amplifier, it triggers the west transmitter module to turn off its amplifier. The west transmitter module may then turn off its amplifier. Both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link break.

FIG. **19** is a flowchart of an exemplary process for restoring components in response to repair of the link break. The pilot NRM signal may be detected at the east RAM (block **1905**). For example, now that the link break has been repaired, the pilot NRM signal outputted by the west RAM can reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal and detect the NRM signal.

The east RAM Raman pumps may be turned on (block **1910**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east RAM Raman pumps to turn on. The east RAM Raman pumps may turn on in response to the signal from the east controller.

The east REM Raman pumps may be turned on (block **1915**). For example, when the east controller detects the pilot NRM signal, the east controller may discontinue the SD signal. The east REM Raman pumps may turn on in response to the discontinuing of the SD signal from the east controller.

The east pilot laser may be modulated to transmit the NRM signal (block **1920**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east pilot laser to modulate with the NRM signal. The east pilot laser may modulate with the NRM signal in response to the signal from the east controller.

The amplifiers of the east receiver and transmitter modules may be turned on (block **1925**). The east receiver module may detect the C-band payload and/or OSC signal, as a result of the link break being repaired, detect no BDI signal, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier.

The BDI may no longer be transmitted on the east-to-west link (block **1930**). For example, when the east transmitter module turns on its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to stop generating the BDI signal.

The pilot NRM signal may be detected at the west RAM (block **1935**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the NRM signal.

The west RAM Raman pumps may be turned on (block **1940**). For example, when the west controller detects the pilot NRM signal from the east RAM, the west controller may send a signal to the west RAM Raman pumps to turn on. The west RAM Raman pumps may turn on in response to the signal from the west controller.

The west REM Raman pumps may be turned on (block **1945**). For example, when the west controller detects the pilot NRM signal, the west controller may discontinue the SD signal. The west REM Raman pumps may turn on in response to the discontinuing of the SD signal from the west controller.

No BDI signal may be detected on the east-to-west link, and the amplifiers of the west receiver and transmitter modules may be turned on (block **1950**). For example, the west receiver module may detect the removal of the BDI signal from the east transmitter module, and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier. As a result, system **1600** may return to normal operation.

Link Break on Local Link

During normal operation (prior to the link break) (e.g., FIG. **16**), west group **1610** and east group **1650** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **1610** may transmit signals to east group **1650** on the west-to-east link, and east group **1650** may transmit signals to west group **1610** on the east-to-west link. During this time, pilot laser **210/340** may be turned on and may output a pilot NRM signal, and Raman pumps **230/360/1632/1670** may be turned on and may output pump power.

Now assume that a link break occurs on the local link connecting the west RAM to the west REM. FIG. **20** is a diagram of exemplary system **1600** in the situation where a link break occurs on the local link. FIG. **21** is a flowchart of an exemplary process for shutting down components in response to the link break. In the description to follow, reference will be made to certain components of west group **1610** and east group **1650**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **1610** will be referred to as the west RAM, and the RAM in east group **1650** will be referred to as the east RAM.

A loss of signals may be detected at west REM (block **2105**). For example, the west REM may detect the loss of the C-band payload, the OSC signal, and the pilot signal.

The west REM Raman pumps may be turned off (block **2110**). For example, in response to the loss of the signals, the west REM may turn off the west REM Raman pumps (regardless of the state of the SD signal), as shown in FIG. **20**.

The loss of the pilot signal may be detected at the east RAM (block **2115**). For example, due to the link break, the pilot signal outputted by the west RAM cannot reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal. Because the pilot signal is generated at 1610 nm, the east controller can differentiate the presence or absence of the pilot signal even in the presence of noise generated by the east Raman pumps, which may be in the range of approximately 1420-1460 nm.

The east RAM Raman pumps may be turned off (block **2120**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east RAM Raman pumps to turn off. The east RAM Raman pumps may turn off in response to the signal from the east controller, as shown in FIG. **20**.

The east REM Raman pumps may be turned off (block **2125**). For example, when the east controller detects the loss of the pilot signal, the east controller may generate the SD signal and send the SD signal to the east REM Raman pumps. The east REM Raman pumps may turn off in response to the SD signal from the east controller, as shown in FIG. **20**.

The east pilot laser may be modulated to transmit the RRF signal (block **2130**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east pilot laser to modulate with the RRF signal.

The east pilot laser may modulate with the RRF signal in response to the signal from the east controller, as shown in FIG. **20**.

The amplifiers of the east receiver and transmitter modules may be turned off (block **2135**). The east receiver module may detect the loss of the C-band payload and/or OSC signal and turn off its amplifier. When the east receiver module turns off its amplifier, it triggers the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier.

A BDI signal may be transmitted on the east-to-west link (block **2140**). For example, when the east transmitter module turns off its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to generate the BDI signal and output the BDI signal to be optically combined with the pilot RRF signal and output on the east-to-west link.

The pilot RRF signal may be detected at the west RAM (block **2145**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the RRF signal.

The west RAM Raman pumps may be turned off (block **2150**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may send a signal to the west RAM Raman pumps to turn off. The west RAM Raman pumps may turn off in response to the signal from the west controller, as shown in FIG. **20**.

The SD signal may be generated (block **2155**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may generate the SD signal and send the SD signal to the west REM Raman pumps. The west REM Raman pumps are already turned off, and remain turned off, as shown in FIG. **20**.

The west pilot laser may be modulated to transmit the NRM signal (block **2160**). For example, when the west controller detects the pilot RRF signal from the east RAM, the west controller may send a signal to the west pilot laser to modulate with the NRM signal. The west pilot laser may modulate with the NRM signal in response to the signal from the west controller, as shown in FIG. **20**.

The BDI signal may be detected and the amplifiers of the west receiver and transmitter modules may be turned off (block **2165**). For example, the west receiver module may detect the BDI signal from the east transmitter module, and turn off its amplifier. When the west receiver module turns off its amplifier, it triggers the west transmitter module to turn off its amplifier. The west transmitter module may then turn off its amplifier. Both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link break.

FIG. **22** is a flowchart of an exemplary process for restoring components in response to repair of the link break. Once the local link break is repaired, the west REM detects the C-band payload, OSC signal, and pilot signal. The west REM may keep the west REM Raman pumps shut down because the SD signal is asserted, but may permit the C-band payload, OSC signal, and pilot signal to be outputted on the west-to-east link.

The pilot NRM signal may be detected at the east RAM (block **2205**). For example, now that the link break has been repaired, the pilot NRM signal outputted by the west RAM can reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal and detect the NRM signal.

The east RAM Raman pumps may be turned on (block **2210**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east RAM Raman pumps to turn on. The east RAM Raman pumps may turn on in response to the signal from the east controller.

The east REM Raman pumps may be turned on (block **2215**). For example, when the east controller detects the pilot NRM signal, the east controller may discontinue the SD signal. The east REM Raman pumps may turn on in response to the discontinuing of the SD signal from the east controller.

The east pilot laser may be modulated to transmit the NRM signal (block **2220**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east pilot laser to modulate with the NRM signal. The east pilot laser may modulate with the NRM signal in response to the signal from the east controller.

The amplifiers of the east receiver and transmitter modules may be turned on (block **2225**). The east receiver module may detect the C-band payload and/or OSC signal, as a result of the link break being repaired, detect no BDI signal, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier.

The BDI may no longer be transmitted on the east-to-west link (block **2230**). For example, when the east transmitter module turns on its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to stop generating the BDI signal.

The pilot NRM signal may be detected at the west RAM (block **2235**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the NRM signal.

The west RAM Raman pumps may be turned on (block **2240**). For example, when the west controller detects the pilot NRM signal from the east RAM, the west controller may send a signal to the west RAM Raman pumps to turn on. The west RAM Raman pumps may turn on in response to the signal from the west controller.

The west REM Raman pumps may be turned on (block **2245**). For example, when the west controller detects the pilot NRM signal, the west controller may discontinue the SD signal. The west REM Raman pumps may turn on in response to the discontinuing of the SD signal from the west controller.

No BDI signal may be detected on the east-to-west link, and the amplifiers of the west receiver and transmitter modules may be turned on (block **2250**). For example, the west receiver module may detect the removal of the BDI signal from the east transmitter module, and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier. As a result, system **1600** may return to normal operation.

Link Breaks on Both West-to-East Link and East-to-West Link

During normal operation (prior to the link break) (e.g., FIG. **16**), west group **1610** and east group **1650** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **1610** may transmit signals to east group **1650** on the west-to-east link, and east group **1650** may transmit signals to west group **1610** on the east-to-west link. During this time, pilot laser **210**/**340** may be turned on and may output a pilot NRM signal, and Raman pumps **230**/**360**/**1632**/**1672** may be turned on and may output pump power.

Now assume that link breaks occur on both the west-to-east link and the east-to-west link. FIG. **23** is a diagram of exemplary system **1600** in the situation where link breaks occur on both the west-to-east link and the east-to-west link. FIG. **24** is a flowchart of an exemplary process for shutting down components in response to the link breaks. In the description to follow, reference will be made to certain components of west group **1610** and east group **1650**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **1610** will be referred to as the west RAM, and the RAM in east group **1650** will be referred to as the east RAM.

The loss of the pilot signal may be detected at the east RAM (block **2410**). For example, due to the link break, the pilot signal outputted by the west RAM cannot reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal. Because the pilot signal is generated at 1610 nm, the east controller can differentiate the presence or absence of the pilot signal even in the presence of noise generated by the east Raman pumps, which may be in the range of approximately 1420-1460 nm.

The east RAM Raman pumps may be turned off (block **2420**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east Raman pumps to turn off. The east Raman pumps may turn off in response to the signal from the east controller, as shown in FIG. **23**.

The east REM Raman pumps may be turned off (block **2430**). For example, when the east controller detects the loss of the pilot signal, the east controller may generate the SD signal and send the SD signal to the east REM Raman pumps. The east REM Raman pumps may turn off in response to the SD signal from the east controller, as shown in FIG. **23**.

The east pilot laser may be modulated to transmit the RRF signal (block **2440**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east pilot laser to modulate with the RRF signal. The east pilot laser may modulate with the RRF signal in response to the signal from the east controller, as shown in FIG. **23**.

The amplifiers of the east receiver and transmitter modules may be turned off (block **2450**). The east receiver module may detect the loss of the C-band payload and/or OSC signal, as a result of the link break, and turn off its amplifier. When the east receiver module turns off its amplifier, it triggers the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier.

A BDI signal may be transmitted on the east-to-west link (block **2460**). For example, when the east transmitter module turns off its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to generate the BDI signal and output the BDI signal to the east WDM. The east WDM may optically combine the BDI signal with the pilot RRF signal and output the combined BDI signal and RRF signal on the east-to-west link. The combined BDI signal and RRF signal will not arrive at west group **1610** due to the link break on the east-to-west link.

Simultaneously, or substantially simultaneously, blocks **2410**-**2460** may be performed by west group **1610**. As a result, both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link breaks.

FIG. **25** is a flowchart of an exemplary process for restoring components in response to repair of the link breaks. Assume, for example, that the east-to-west link is repaired first. The pilot RRF signal may be detected at the west RAM (block **2505**). For example, now that the link break on the east-to-west link has been repaired, the pilot RRF signal outputted by the east RAM can reach the west RAM. The west controller (within the west RAM) may monitor the presence of the pilot signal and detect the RRF signal. In response to the pilot RRF signal, the west controller may keep the west RAM and REM Raman pumps turned off.

The west pilot laser may be modulated to transmit the NRM signal (block **2510**). For example, the west controller may send a signal to the west pilot laser to modulate with the NRM signal. The west pilot laser may modulate with the NRM signal in response to the signal from the west controller.

The BDI signal may be detected on the east-to-west link and the transmitting of the BDI signal on the west-to-east link may be stopped (block **2515**). For example, the west receiver module may detect the restoration of the C-band payload and/or the OSC signal, and detect the BDI signal sent from east group **1650**. The west receiver module may keep its amplifier turned off and signal the west transmitter module to stop transmitting the BDI signal.

When the west-to-east link is repaired, the pilot NRM signal may be detected at the east RAM (block **2520**). For example, now that the link break on the west-to-east link has been repaired, the pilot NRM signal outputted by the west RAM can reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal and detect the NRM signal.

The east RAM Raman pumps may be turned on (block **2525**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east RAM Raman pumps to turn on. The east RAM Raman pumps may turn on in response to the signal from the east controller.

The east REM Raman pumps may be turned on (block **2530**). For example, when the east controller detects the pilot NRM signal, the east controller may discontinue the SD signal. The east REM Raman pumps may turn on in response to the discontinuing of the SD signal from the east controller.

The east pilot laser may be modulated to transmit the NRM signal (block **2535**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east pilot laser to modulate with the NRM signal. The east pilot laser may modulate with the NRM signal in response to the signal from the east controller.

No BDI signal may be detected, and the amplifiers of the east receiver and transmitter modules may be turned on (block **2540**). The east receiver module may detect restoration of the C-band payload and/or the OSC signal on the west-to-east link, as a result of the link break being repaired, detect no BDI signal, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier.

The BDI may no longer be transmitted on the east-to-west link (block **2545**). For example, when the east transmitter module turns on its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to stop generating the BDI signal.

The pilot NRM signal may be detected at the west RAM (block **2550**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the NRM signal.

The west RAM Raman pumps may be turned on (block **2555**). For example, when the west controller detects the pilot

NRM signal from the east RAM, the west controller may send a signal to the west RAM Raman pumps to turn on. The west RAM Raman pumps may turn on in response to the signal from the west controller.

The west REM Raman pumps may be turned on (block **2560**). For example, when the west controller detects the pilot NRM signal, the west controller may discontinue the SD signal. The west REM Raman pumps may turn on in response to the discontinuing of the SD signal from the west controller.

No BDI signal may be detected on the east-to-west link, and the amplifiers of the west receiver and transmitter modules may be turned on (block **2565**). For example, the west receiver module may detect the removal of the BDI signal from the east transmitter module, and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier. As a result, system **1600** may return to normal operation.

Link Break on Local Transmit Link

During normal operation (prior to the link break) (e.g., FIG. **16**), west group **1610** and east group **1650** may exchange signals on the west-to-east link and the east-to-west link. For example, west group **1610** may transmit signals to east group **1650** on the west-to-east link, and east group **1650** may transmit signals to west group **1610** on the east-to-west link. During this time, pilot laser **210/340** may be turned on and may output a pilot NRM signal, and Raman pumps **230/360/1632/1672** may be turned on and may output pump power.

Now assume that a link break occurs on the local transmit link located between the west BMM/OAM and the west RAM. FIG. **26** is a diagram of exemplary system **1600** in the situation where link breaks occur on the local transmit link. FIG. **27** is a flowchart of an exemplary process for shutting down components in response to the link break. In the description to follow, reference will be made to certain components of west group **1610** and east group **1650**. These components will be referred to as west and east components, respectively. For example, the RAM in west group **1610** will be referred to as the west RAM, and the RAM in east group **1650** will be referred to as the east RAM.

A loss of signals (e.g., C-band payload and/or OSC signal) may be detected at the west RAM (block **2705**). For example, due to the link break, the C-band payload and OSC signal outputted by the west BMM/OAM cannot reach the west RAM. The west controller (within the west RAM) may detect the absence of the C-band payload and/or OSC signal.

The west RAM Raman pumps, the west OSC laser, and the west pilot laser may be turned off (block **2710**). For example, when the west controller detects the loss of the C-band payload and/or OSC signal, the west controller may send signals to the west RAM Raman pumps, the west OSC laser, and the west pilot laser to turn off. The west RAM Raman pumps, the west OSC laser, and the west pilot laser may turn off in response to the signals from the west controller, as shown in FIG. **26**.

The west REM Raman pumps may be turned off (block **2715**). For example, when the west controller detects the loss of the C-band payload and/or OSC signal, the west controller may generate the SD signal and send the SD signal to the west REM Raman pumps. The west REM Raman pumps may turn off in response to the SD signal from the west controller, as shown in FIG. **26**.

The loss of the pilot signal may be detected at the east RAM (block **2720**). For example, since the west pilot laser has been turned off, there is no pilot signal to reach the east RAM. The east controller (within the east RAM) may monitor the presence or absence of the pilot signal. In this case, the east controller may detect the absence of the pilot signal.

The east RAM Raman pumps may be turned off (block **2725**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east RAM Raman pumps to turn off. The east RAM Raman pumps may turn off in response to the signal from the east controller, as shown in FIG. **26**.

The east REM Raman pumps may be turned off (block **2730**). For example, when the east controller detects the loss of the pilot signal, the east controller may generate the SD signal and send the SD signal to the east REM Raman pumps. The east REM Raman pumps may turn off in response to the SD signal from the east controller, as shown in FIG. **26**.

The east pilot laser may be modulated to transmit the RRF signal (block **2735**). For example, when the east controller detects the loss of the pilot signal, the east controller may send a signal to the east pilot laser to modulate with the RRF signal. The east pilot laser may modulate with the RRF signal in response to the signal from the east controller, as shown in FIG. **26**.

The amplifiers of the east receiver and transmitter modules may be turned off (block **2740**). The east receiver module may detect the loss of the C-band payload and/or OSC signal and turn off its amplifier. When the east receiver module turns off its amplifier, it triggers the east transmitter module to turn off its amplifier. The east transmitter module may then turn off its amplifier.

A BDI signal may be transmitted on the east-to-west link (block **2745**). For example, when the east transmitter module turns off its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to generate the BDI signal and output the BDI signal to the east WDM. The east WDM may optically combine the BDI signal with the pilot RRF signal and output the combined BDI signal and RRF signal on the east-to-west link.

The BDI signal may be detected and the amplifiers of the west receiver and transmitter modules may be turned off (block **2750**). For example, the west receiver module may detect the BDI signal from the east transmitter module, and turn off its amplifier. When the west receiver module turns off its amplifier, it triggers the west transmitter module to turn off its amplifier. The west transmitter module may then turn off its amplifier. Both the west-to-east and the east-to-west links are now completely safe. In other words, a technician may safely repair the link break.

FIG. **28** is a flowchart of an exemplary process for restoring components in response to repair of the link break. Signals (e.g., C-band payload and/or OSC signal) may be detected at the west RAM and west OSC laser may be turned on (block **2805**). For example, due to repair of the link break, the C-band payload and OSC signal outputted by the west BMM/OAM can now reach the west RAM. The west controller (within the west RAM) may detect the restoration of the C-band payload and/or OSC signal.

The west pilot laser may be turned on and modulated to transmit the NRM signal (block **2810**). For example, the west controller may detect the pilot RRF signal from the east RAM. In response, the west controller may send a signal to the west pilot laser to turn on and modulate with the NRM signal. The west RAM and REM Raman pumps may remain turned off.

The pilot NRM signal may be detected at the east RAM (block **2815**). For example, now that the link break has been repaired, the pilot NRM signal outputted by the west RAM can reach the east RAM. The east controller (within the east RAM) may monitor the presence of the pilot signal and detect the NRM signal.

The east RAM Raman pumps may be turned on (block **2820**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east RAM Raman pumps to turn on. The east RAM Raman pumps may turn on in response to the signal from the east controller.

The east REM Raman pumps may be turned on (block **2825**). For example, when the east controller detects the pilot NRM signal, the east controller may discontinue the SD signal. The east REM Raman pumps may turn on in response to the discontinuing of the SD signal from the east controller.

The east pilot laser may be modulated to transmit the NRM signal (block **2830**). For example, when the east controller detects the pilot NRM signal, the east controller may send a signal to the east pilot laser to modulate with the NRM signal. The east pilot laser may modulate with the NRM signal in response to the signal from the east controller.

No BDI signal may be detected, and the amplifiers of the east receiver and transmitter modules may be turned on (block **2835**). The east receiver module may detect the C-band payload and/or OSC signal, as a result of the link break being repaired, detect no BDI signal, and turn on its amplifier. When the east receiver module turns on its amplifier, it triggers the east transmitter module to turn on its amplifier. The east transmitter module may then turn on its amplifier.

The BDI signal may no longer be transmitted on the east-to-west link (block **2840**). For example, when the east transmitter module turns on its amplifier, the east transmitter module may trigger the east OSC source, associated with the east transmitter module, to stop generating the BDI signal.

The pilot NRM signal may be detected at the west RAM (block **2845**). For example, the west controller (within the west RAM) may monitor the signals transmitted on the east-to-west link to detect the presence of the pilot signal and to determine whether the pilot signal includes the RRF signal or the NRM signal. In this case, the west controller detects the presence of the NRM signal.

The west RAM Raman pumps may be turned on (block **2850**). For example, when the west controller detects the pilot NRM signal from the east RAM, the west controller may send a signal to the west RAM Raman pumps to turn on. The west RAM Raman pumps may turn on in response to the signal from the west controller.

The west REM Raman pumps may be turned on (block **2855**). For example, when the west controller detects the pilot NRM signal, the west controller may discontinue the SD signal. The west REM Raman pumps may turn on in response to the discontinuing of the SD signal from the west controller.

No BDI signal may be detected on the east-to-west link, and the amplifiers of the west receiver and transmitter modules may be turned on (block **2860**). For example, the west receiver module may detect the removal of the BDI signal from the east transmitter module, and turn on its amplifier. When the west receiver module turns on its amplifier, it triggers the west transmitter module to turn on its amplifier. The west transmitter module may then turn on its amplifier. As a result, system **1600** may return to normal operation.

Conclusion

Implementations described herein may facilitate shutdown and recovery in response to link breaks. Table 1 summarizes the operation described above and the effects on the RAM and REM Raman pumps, the OSC laser, and the pilot laser. The OSC laser column is applicable for RAMs that include OSC lasers. The REM pumps column is applicable for configurations that incorporate a REM.

TABLE 1

State Description	Shutdown Event	RAM Pumps	REM Pumps	OSC Laser	Pilot Laser
No pilot signal (RRF or NRM) detected and C-band or OSC signal detected at BMM/OAM. This indicates a fiber break in the main fiber span.	YES	OFF	OFF	ON	RRF
Neither C-band nor OSC detected at the BMM/OAM port. This indicates a fiber break between the local BMM/OAM and RAM.	YES	OFF	OFF	OFF	OFF
RRF signal detected and C-band or OSC signal detected at BMM/OAM. This indicates a fiber break has been detected by the RX side of the upstream amplifier.	YES	OFF	OFF	ON	NRM
NRM signal detected and C-band or OSC signal detected at BMM/OAM. No fiber break.	NO	ON	ON	ON	NRM

When a link break is detected due to the loss of the pilot signal (RRF and NRM), and there is no link break on the local link between the BMM/OAM and the RAM, the RAM may shut down its pumps and modulate its pilot laser to output the RRF signal to the RAM downstream of the break. If applicable, the RAM may also shut down the REM pumps by asserting the SD signal. The pumps are turned off to provide a safe condition as well as to remove any noise from the BMM/OAM receiver.

When a link break is detected at the BMM/OAM due to a loss of the C-band payload and/or the OSC signal, the RAM may shut down its pumps, OSC laser, and pilot laser. If applicable, the RAM may also shut down the REM pumps by asserting the SD signal. The OSC laser may be shut down because without a valid OSC input signal, the OSC laser may generate noise on the OSC channel. This noise may be detected by the far end BMM/OAM receiver as optical energy that the BMM/OAM may confuse as the OSC signal, causing the BMM/OAM not to output a BDI signal. Without this BDI signal, the amplifier associated with the local transmitter module may not turn off, resulting in an unsafe condition. Accordingly, the pilot laser may be turned off to simulate a link break on the main fiber span for the remote RAM.

When the RRF pilot signal is detected and there is no link break on local link between the BMM/OAM and the RAM, the RAM may shut down its pumps and modulate its pilot laser to output a NRM signal to the far end RAM. If applicable, the RAM may also shut down the REM pumps by asserting the SD signal.

When the NRM pilot signal is detected and there is no fiber break on the local link between the BMM/OAM and the RAM, the RAM may turn on its pumps and modulate its pilot laser to output a NRM signal to the far end RAM. If applicable, the RAM may also enable the REM pumps by de-asserting the SD signal. When the RAM de-asserts the SD signal, the REM pumps may be turned on only if there is no link break in the short fiber span between the RAM and the REM. In other words, if the REM detects either the pilot signal, the C-band payload, or the OSC signal from the RAM and the SD signal is de-asserted, then the REM may turn on its pumps.

The foregoing description provides illustration and description, but is not intended to be exhaustive or to limit the invention to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention.

For example, while series of blocks have been described with regard to FIGS. **5**, **6**, **8**, **9**, **11**, **12**, **14**, **15**, **18**, **19**, **21**, **22**, **24**, **25**, **27**, and **28**, the order of the blocks may be modified in other implementations. Further, non-dependent blocks may be performed in parallel.

Further, the term "approximately" has been used throughout the description and is intended to mean the exact number or range that follows the term or a number within a particular threshold of the number or range that follows the term.

Also, while signals of particular exemplary wavelengths have been described, one or more of these signals may have a different wavelength, or operate within a different range of wavelengths, in other implementations.

Even though particular combinations of features are recited in the claims and/or disclosed in the specification, these combinations are not intended to limit the disclosure of the invention. In fact, many of these features may be combined in ways not specifically recited in the claims and/or disclosed in the specification. Although each dependent claim listed below may directly depend on only one other claim, the disclosure of the invention includes each dependent claim in combination with every other claim in the claim set.

No element, act, or instruction used in the present application should be construed as critical or essential to the invention unless explicitly described as such. Also, as used herein, the article "a" is intended to include one or more items. Where only one item is intended, the term "one" or similar language is used. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.

What is claimed is:

1. A communication system, comprising:

a first optical source configured to supply a first optical signal to a first optical link, the first optical signal propagating in a first direction along the first optical link;

a second optical source configured to supply a second optical signal to a second optical link, the second optical signal propagating in the first direction along the second optical link;

a first control circuit configured to:

detect an absence of the first optical signal on the first optical link resulting from a break in the first optical link, and

output a first signal in response to detecting the absence of the first optical signal;

a third optical source configured to supply a third optical signal to the second optical link in response to the first signal, the third optical signal propagating in a second direction different than the first direction;

a second control circuit configured to:

detect a presence of the third optical signal on the second optical link, and

output a second signal in response to detecting the presence of the third optical signal; and

a fourth optical source configured to supply a plurality of fourth optical signals to the second optical link, the plurality of fourth optical signals propagating along the second optical link in the second direction;

an optical supervisory channel transmitter configured to supply an optical supervisory channel to the second optical link, the optical supervisory channel propagating in the second direction and carrying information indicative of the break in the first optical link; and

a transmitter amplifier coupled to the first optical link,

where the second optical source is disabled in response to the second optical signal, and the second optical signal provides Raman gain to the fourth optical signal, and the transmitter amplifier is disabled in response to the optical supervisory channel.

2. The communication system of claim **1**, where each of the first optical signal and the third optical signal has a wavelength of approximately 1610 nm.

3. The communication system of claim **1**, where the third optical source is configured to modulate the third optical signal as a modulated third optical signal based on the first signal, the modulated third optical signal indicating, to the second control circuit, to disable the second optical source, where the second control circuit is configured to output the second signal in response to detecting the modulated third optical signal.

4. The communication system of claim **1**, further comprising:

a fifth optical source configured to supply a fifth optical signal to the first optical link, the fifth optical signal propagating in the second direction along the first optical link.

5. The communication system of claim **4**, where the first control circuit is further configured to output a third signal in response to detecting the absence of the first optical signal, where the fifth optical source is disabled in response to the third signal.

6. The communication system of claim **5**, where the first control circuit is further configured to:

detect a presence of the first optical signal on the first optical link, and

output a fourth signal in response to detecting the presence of the first optical signal on the first optical link, where the fifth optical source is enabled in response to the fourth signal.

7. The communication system of claim **4**, where the second control circuit is further configured to output a third signal in response to detecting the third optical signal, the third signal causing the first optical source to modulate the first optical signal as a modulated first optical signal, the modulated first optical signal indicating, to the first control circuit, to enable the fifth optical source.

8. The communication system of claim **7**, where the first control circuit is further configured to:

detect a presence of the modulated first optical signal on the first optical link, and

output a fourth signal in response to detecting the presence of the modulated first optical signal, where the fifth optical signal is enabled in response to the fourth signal.

9. The communication system of claim **1**, where the first control circuit is further configured to:

detect a presence of the first optical signal on the first optical link, and

output a third signal in response to detecting the presence of the first optical signal on the first optical link, where the third signal causes the third optical source to modulate the third optical signal as a modulated third optical signal, the modulated third optical signal indicating, to the second control circuit, to enable the second optical source.

10. The communication system of claim **9**, where the second control circuit is further configured to:

detect a presence of the modulated third optical signal on the second optical link, and

output a fourth signal in response to detecting the presence of the third optical signal, where the second optical source is enabled in response to the fourth signal.

11. The communication system of claim **1**, further comprising:

a fifth optical source supplying a fifth optical signal to the second optical link, the fifth optical signal propagating in the second direction along the second optical link.

12. The communication system of claim **11**, where the first control circuit is further configured to output a third signal in response to detecting the absence of the first optical signal, where the fifth optical source is disabled in response to the third signal.

13. The communication system of claim **12**, where the first control circuit is further configured to:

detect a presence of the first optical signal on the first optical link, and

output a fourth signal in response to detecting the presence of the first optical signal on the first optical link, where the fifth optical source is enabled in response to the fourth signal.

14. The communication system of claim **11**, where the second control circuit is further configured to output a third signal in response to detecting the presence of the third optical signal, the third signal causing the first optical source to modulate the first optical signal as a modulated first optical signal, the modulated first optical signal indicating to the first control circuit to enable the fifth optical source.

15. The communication system of claim **1**, further comprising:

a fifth optical source supplying a fifth optical signal to the first optical link, the fifth optical signal propagating in the first direction along the first optical link.

16. The communication system of claim **15**, where the second control circuit is further configured to output a third signal in response to detecting the third optical signal, where the fifth optical source is disabled in response to the third signal.

17. The communication system of claim **1**, further comprising:

a fifth optical source supplying a fifth optical signal to the second optical link, the fifth optical signal propagating in the second direction along the second optical link; and

a sixth optical source supplying a sixth optical signal to the first optical link, the sixth optical signal propagating in the first direction along the first optical link.

18. A communication system, comprising:

a first control circuit configured to detect a break on a first optical link;

a pilot laser configured to supply a first optical signal on a second optical link in response to detecting the break on the first optical link, the first optical signal propagating in a first direction on the second optical link;

a second control circuit configured to:

detect a presence of the first optical signal on the second optical link, and

output a first control signal in response to detecting the presence of the first optical signal;

a Raman pump configured to supply a second optical signal on the second optical link, the second optical signal propagating in a second direction opposite the first direction,

an optical supervisory channel transmitter configured to supply a first optical supervisory channel to the second optical link, the first optical supervisory channel configured to carry information indicative of the break in the first optical link; and

a transmitter amplifier coupled to the first optical link,

where the Raman pump is disabled in response to the first control signal, and the transmitter amplifier is disabled in response to the first optical supervisory channel.

19. The communication system of claim **18**, further comprising:

another Raman pump configured to supply a third optical signal on the second optical link, the third optical signal propagating in the first direction.

20. The communication system of claim **18**, where the first control circuit is further configured to detect repair of the break on the first optical link;

where the pilot laser is further configured to supply a third optical signal on the second optical link in response to detecting the repair of the break on the first optical link;

where the second control circuit is further configured to:

detect a presence of the third optical signal on the second optical link, and

output a second control signal in response to detecting the presence of the third optical signal;

where the Raman pump is enabled in response to the second control signal;

where the optical supervisory channel transmitter is further configured to:

supply a second optical supervisory channel to the second optical link,

wherein the second optical supervisory channel is further configured to carry information indicative of the repair in the first optical link; and

where the transmitter amplifier is enabled in response to the second optical supervisory channel.

21. A method, comprising:

supplying a first optical signal on a first optical link, the first optical signal propagating in a first direction on the first optical link;

supplying a second optical signal on the first optical link, the second optical signal propagating in a second direction, that is opposite the first direction, on the first optical link;

detecting an absence of the first optical signal on the first optical link resulting from a break in the first optical link;

disabling the supplying of the second optical signal on the first optical link in response to detecting the absence of the first optical signal;

supplying a third optical signal on a second optical link in response to detecting the absence of the first optical signal, the third optical signal propagating in the second direction on the second optical link;

supplying a fourth optical signal on the second optical link, the fourth optical signal propagating in the first direction on the second optical link;

detecting a presence of the third optical signal on the second optical link;

disabling the supplying of the fourth optical signal on the second optical link in response to detecting the presence of the third optical signal;

supplying an optical supervisory channel to the second optical link in response to the break in the first optical link; and

disabling a transmitter amplifier in response to the optical supervisory channel.

22. The method of claim 21, further comprising:

detecting a presence of the first optical signal on the first optical link; and

enabling the supplying of the second optical signal on the first optical link in response to detecting the presence of the first optical signal.

23. The method of claim 21, further comprising:

supplying a fifth optical signal on the first optical link, the fifth optical signal propagating in the first direction on the first optical link; and

disabling the supplying of the fifth optical signal on the first optical link in response to detecting the presence of the third optical signal.

24. The method of claim 21, further comprising:

supplying a fifth optical signal on the second optical link, the fifth optical signal propagating in the second direction on the second optical link; and

disabling the supplying of the fifth optical signal on the second optical link in response to detecting the absence of the first optical signal.

25. The method of claim 21, further comprising:

supplying a fifth optical signal on the first optical link, the fifth optical signal propagating in the first direction on the first optical link;

disabling the supplying of the fifth optical signal on the first optical link in response to detecting the presence of the third optical signal;

supplying a sixth optical signal on the second optical link, the sixth optical signal propagating in the second direction on the second optical link; and

disabling the supplying of the sixth optical signal on the second optical link in response to detecting the absence of the first optical signal.

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